ENERGY TECHNOLOGY INNOVATION POLICY

A joint project of the Science, Technology and Public Policy Program and the Environment and Natural Resources Program
Belfer Center for Science and International Affairs

HARVARD UNIVERSITY

JOHN F. KENNEDY
SCHOOL OF GOVERNMENT

Setting Priorities in Energy Innovation Policy: Lessons for the UK

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Discussion Paper 2008-07
October 2008

energytechnologypolicy.org

Setting Priorities in Energy Innovation Policy: Lessons for the UK[1]

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ETIP Discussion Paper Series
Belfer Center for Science and International Affairs

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October 2008

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[1] An earlier version of this paper will be published as: Watson, J. (2009). Technology Assessment and Innovation Policy. in G. MacKerron and I. Scrase, Eds. Energy for The Future, Palgrave-Macmillan.

Citation

This paper may be cited as: Watson, Jim. “Setting Priorities in Energy Innovation Policy: Lessons for the UK.” Discussion Paper 2008-08, Cambridge, Mass.: Belfer Center for Science and International Affairs, August 2008. Comments are welcome and may be directed to James Watson at the Sussex Energy Group, SPRU – University of Sussex, Brighton, East Sussex, BN1 9QE, UK.

Energy Technology Innovation Policy

The overarching objective of the Energy Technology Innovation Policy (ETIP) research group is to determine and then seek to promote adoption of effective strategies for developing and deploying cleaner and more efficient energy technologies, primarily in three of the biggest energy-consuming nations in the world: the United States, China, and India. These three countries have enormous influence on local, regional, and global environmental conditions through their energy production and consumption.

ETIP researchers seek to identify and promote strategies that these countries can pursue, separately and collaboratively, for accelerating the development and deployment of advanced energy options that can reduce conventional air pollution, minimize future greenhouse-gas emissions, reduce dependence on oil, facilitate poverty alleviation, and promote economic development. ETIP's focus on three crucial countries rather than only one not only multiplies directly our leverage on the world scale and facilitates the pursuit of cooperative efforts, but also allows for the development of new insights from comparisons and contrasts among conditions and strategies in the three cases.

Executive Summary

The transition towards more sustainable, low carbon societies will require the development and deployment of a range of new and existing energy technologies. These include centralised supply side options such as carbon capture and storage, infrastructure technologies such as decentralised energy networks, and technologies adopted by consumers such as LED lighting, cleaner vehicles and micro-generation.

This paper analyses the role of governments in supporting this process and draws on experience from Europe, the USA and Japan. The paper’s starting point is the common assertion that governments should avoid providing targeted support to particular technologies. Instead, they should set general frameworks to encourage more sustainable innovation, for example by creating carbon markets. The practice of ’picking winners’ should therefore be avoided because governments are not best placed to decide which technologies to fund.

The paper challenges this argument on a number of grounds. First, the resources that governments can devote to sustainable energy innovation are limited. If there is no attempt to prioritise how these resources are used, there is a risk that they will be spread too thinly. Second, the urgency of climate change means that innovation and deployment may be too slow if there is an excessive reliance on the carbon market. Carbon markets such as the EU emissions trading scheme are in their infancy, and have yet to demonstrate that they are strong enough to promote significant low carbon innovation. Third, even if there were a high carbon price, it is unlikely that this would be sufficient to develop those technologies that are not already close to commercial status. Generic policy incentives such as carbon prices tend to favour near market technologies.

Having discussed the rationales for more specific government support for sustainable energy technologies, the paper explores some of the criteria that could be used by policy makers to prioritise this support. These include the costs and risks of different technologies; the different development stage of each technology, diversity within portfolios of technologies; and the role of industrial policy. Whilst many of these criteria are included within policy development processes, the paper argues that it is often hard to find an overall rationale for the priorities that emerge.

The paper concludes with five key implications for energy innovation policy. These are particularly aimed at UK policy, but are also relevant to other countries too:

- First, government funding for more sustainable energy technologies needs to increased and rebalanced. Rebalancing would give a greater support to technologies facing the ‘valley of death’ between demonstration and commercial deployment. In the absence of public funding, taking innovations across this valley of death can be too costly (and hence too risky) for many firms. UK policy is now moving in the right direction, though more needs to be done to align the size and profile of budgets with claims to international leadership on climate change.
- Second, government funding needs to be more technology-specific. Generic incentives such as carbon emissions trading schemes are necessary, but are not sufficient to develop and deploy the range of technologies required. Research shows that technology-specific approaches work. However, in order to pursue these successfully, policy makers will need enough independence to decide when to discontinue support – often in the face of disappointed lobbies.
- Third, the process of deciding which technologies to prioritise needs to be more transparent. Whilst the UK government has published a range of documents that focus on specific areas such as renewables and energy efficiency, there is no visible, overarching strategy. Such a strategy should establish what criteria are important for decision making – and how these criteria have been used to inform the development of policies and incentives.
- Fourth, policy needs to strengthen its capacity for evaluation of technology support programmes. In common with other governments, the UK policy system conducts some evaluations. However, this process does not appear to be a systematic one. Evaluation is

critical so that failures do not threaten government legitimacy, but are seen as opportunities to learn.

- Finally, innovation policies need to deal with the locked in-nature of current energy systems. Whilst energy infrastructures, institutions and policies were developed to meet important social goals, radical change is likely to be required to tackle climate change effectively. Government policy therefore needs to open up energy systems to more radical technologies and business models, and ensure that institutions and common infrastructures facilitate their deployment.

1. Introduction

The transition to sustainable, low carbon societies will require the development and deployment of a range of new and existing energy technologies. These technologies will required to deliver substantial reductions in greenhouse gas emissions, for example by lowering the carbon intensity of energy use or increasing energy efficiency. They span centralised supply-side options such as carbon capture and storage, infrastructure technologies such as decentralised energy networks, and technologies adopted by consumers such as LED lighting, cleaner vehicles and micro-generation.

This presents a series of important challenges for government policy. Many of these technologies will not be developed in the first place without government intervention and assistance. Strong policy incentives are also required to ensure that more sustainable technologies are demonstrated at scale and deployed in commercial markets.

The UK provides an important illustration of these challenges. Whilst the UK government has played a leading international role in climate change policy, this position is now in jeopardy. In common with the situation in many other industrialised economies, UK carbon emissions are rising. The declines of the 1990s that underpinned political leadership were due to a switch from coal to gas in power generation – a switch that has run out of momentum. High fossil fuel prices have led to a greater emphasis on energy security and affordability – goals that can reinforce or conflict with climate change mitigation.

Current policy therefore needs to be more effective in purposefully steering market behaviour so that more sustainable technologies are developed – and investments are made in markets. This paper discusses how governments should prioritise the support given to different sustainable energy technologies, and what incentives should be provided to speed up the processes of development and deployment. Whilst the rationale for the paper is to inform UK policy in particular, the paper also draws on innovation policy experience from the USA, other European countries and Japan.

The paper first summarises some important insights about innovation processes, and their implications for policies to support more sustainable energy technologies. The paper then considers the case for government involvement – and the reasons why it is difficult for government policies to remain technology neutral. This is followed by a detailed discussion of some criteria which could help governments make choices about which technologies to support, and how to support them. This discussion focuses on the technology costs and risks, the stage of development of technologies, the role of diversity within technology portfolios, and the extent to which industrial policy and energy policy should be integrated. Finally, the paper concludes with some implications for UK energy innovation policies.

2. Understanding Energy Innovation

The effectiveness of policies to support innovation depends on the extent to which they are rooted in an understanding of how innovation works. As the large body of literature on the subject indicates, the innovation occurs through a complex set of processes. This paper does not allow enough space to discuss this literature in detail. Instead, the discussion will highlight some of the key insights that have particular relevance to government innovation strategies, with a particular emphasis on new and emerging low carbon technologies.

Innovation includes several distinctive but related stages – from research and development (R&D) to prototyping, demonstration, commercialisation and deployment. Early conceptions of innovation characterised the process of moving through these stages from R&D to deployment as a linear one. However, this 'linear model' was soon abandoned as too simplistic by many of those engaged in innovation as well as some of those trying to understand and support it.

More than a decade ago, Roy Rothwell (1994) showed how the understanding of innovation has changed over time. He characterised five different models of organisation. Following the second world war, innovation in industrialised economies tended to use a 'technology push' model in which new product and process innovations were pushed into the market. During the 1960s, this gave way to a second 'demand pull' model which was characterised by market and customer-focused innovation. In this model, R&D served market needs and was therefore more reactive. During the 1970s, the understanding of the innovation process changed again. It was recognised that neither 'technology' push nor 'demand pull' provided accurate explanations of successful innovation. Therefore a third 'coupled' model of innovation became common in which both played a role. R&D and marketing functions were linked together by feedback loops which emphasised mutual learning between them.

The fourth model that emerged in the late 1980s drew heavily on the successful experience of Japanese firms. This took integration further – with strong links to supply chains and to important 'lead customers' for new products. It also included parallel activities by different functional departments within innovating firms. Finally, a fifth networked model of innovation was put forward by Rothwell to characterise changes observed in the 1990s. As he argues, this builds on elements of the fourth model, with further integration of activities, closer relationships with suppliers and customers. The emphasis in the fifth model is on what Rothwell calls 'lean innovation' (Rothwell 1994: 23) which is characterised by speed and flexibility of product development to respond to changing needs. A key feature of the later models is that they explicitly incorporate feedback – a process that is sometimes referred to as 'learning by doing'. Lessons from prototyping, demonstration and the commercial deployment of new technologies are used to underpin further innovation. This might yield further improvements or solve problems that become apparent when technologies are incorporated into commercial products.

This increasingly sophisticated understanding of innovation is further enhanced by a recognition that the scale and scope of innovation varies widely. Chris Freeman (1992) drew attention to the contrast between incremental innovations which lead to improvements in existing products, and radical innovations which yield new inventions and/or methods of production. He also showed how a series of radical innovations in different parts of the economy can lead to changes in technological systems, for example through the adoption of a series of low carbon technologies (Stern 2006: Chapter 16). Going further, changes of techno-economic paradigm can occur when a set of innovations has a pervasive effect on the whole economy. An example of this is the widespread uptake of information technology (IT).

Many studies of the innovation process emphasise economics as a key driver for technical change. However, this does not mean that the relationship between relative costs and the success of new innovations is a simple one. Freeman and Louça (2001) note that wide ranging shifts in techno economic paradigm are driven by the prospect of 'super profits' for innovators. Such super profits help to offset the risks of investing in radical new innovations. In the early stages of new innovations, however, incumbent technologies can have a price advantage. For example, when electric lighting was first introduced in the 1880s, it was four times more expensive than gas lighting (Pearson and Fouquet 2006). Parity in cost was only achieved in the 1920s. Whilst the diffusion of electric lighting was driven by the potential for cost reductions, it also occurred due to other non-economic benefits it offered to users such as convenience and novelty.

These and other insights have led to a number of standard rationales for government intervention and/or financial support for innovation. Most of these focus on the existence of one or more market failures (e.g. Scott and Steyn 2001; Jaffe, Newell et al. 2005). In the field of sustainable energy, two market failures are most commonly cited. First, that the social costs of carbon emissions from the energy system are not fully internalised. This means that technologies that emit less carbon are at a disadvantage. Second, that there is a tendency of the private sector to under-invest in R&D because individual firms cannot fully capture the returns from their investments. Further market failures are sometimes added to these two – for example, the tendency of markets to under-invest in other relevant public goods such as energy security. The natural response to the first two market failures is to create a policy framework that emphasises market mechanisms (such as emissions trading) that prices carbon emissions and provides government funding for R&D.

However, government technology policies have to do more than fund basic R&D and internalise the social costs of carbon emissions (Bonvillian 2007). There may be a need for government to support other stages of the innovation process. For example, there has been increasing attention on the 'valley of death' that faces developers as they try to move technologies from demonstration or prototype phase to incorporation in commercial products (Department of Trade and Industry 2004; Gallagher, Holdren et al. 2006). For example, the UK's Carbon Trust has a particular focus on supporting innovations through this stage. This support takes a number of forms including technology accelerators, early stage investments in low carbon technology businesses and business incubators.

Beyond this, there are several further rationales for intervention that stem from more than just market failures. These rationales often stem from an innovation systems perspective which analyses technologies alongside the actors, institutions and policies that shape innovation. Technology systems have been defined in a number of different ways. For example, there is extensive literature on national innovation systems which focuses on innovation within a particular country (e.g. Nelson 1993). Meanwhile, other literature focuses on technological systems which focus on a particular technology or group of technologies (e.g. Jacobsson and Bergek 2004).

In some cases, analysts taking such a systemic approach explicitly reject market failures as a sound basis for policy. Instead, they focus on how policy can compensate for broader 'system failures'. For example, Stan Metcalfe argues that:

> The state is not promoting individual innovation events in this view rather it is setting the framework conditions in which innovation systems can better self-organize across the range of activities in an economy. Because systems are defined by components interacting within boundaries, it follows that a system failure policy seeks to address missing components, missing connections and misplaced boundaries (Metcalfe 2004: 19).

This broader view does appear to have been accepted to some extent within government. In 2003, an economics paper by the UK Department of Trade and Industry acknowledged system failures. It advocated support for networks of firms involved in the innovation process, and identified the need to counter market, technological and regulatory uncertainty which can make innovation particularly risky (Department of Trade and Industry 2003). A similar acknowledgement appears in a more recent innovation strategy from the Department of Transport (Department for Transport 2007).

Such system failures are particularly important for low carbon and sustainable technologies (Foxon 2003; Stern 2006). The adoption of some of these requires both technological change and institutional change. For example, the diffusion of smart metering technology is not just a simple technical challenge but also implies a new approach to information provision to energy consumers and new information-technology infrastructure. Others require new links between established but hitherto separate actors within the innovation system. For example, carbon capture and storage (CCS) technologies require new collaborations between utilities, oil and gas companies and power equipment companies. Plug in hybrid vehicles require planning and co-operation between vehicle manufacturers and electricity companies. Novel technologies such as CCS can also require amendments to existing regulations (e.g. those that govern marine pollution).

One of the most important system failures for sustainable technologies is ‘lock-in’ (Unruh 2000). This draws attention to the fact that many parts of the energy system consist of long lived capital assets including power stations, gas pipelines and buildings. Furthermore, these are supported by systems of rules, regulations and institutions that co-ordinate energy flows, market relationships and investment decisions. Technologies and institutions co-evolve and are closely integrated (Geels 2004; Weber and Hemmelskamp 2005). New technologies that respond to policy needs to reduce carbon emissions or enhance energy security can therefore face pervasive barriers to adoption because the energy system is not set up to accommodate them. Innovation policy can therefore be ineffective if it does not take such pervasive barriers into account.

3. Not Picking Winners?

In the light of the discussion so far, the key issue is not whether subsidies, incentives or selective market support for certain technologies or types of technologies should be given in principle. Rather, it is the process by which government decides which options to support and the mechanisms through which it supports them. The debate on this issue is opaque. A default position that has been adopted by some British Ministers and civil servants is that it is not the task of policy to pick winners – whether for investment (e.g. for new power plants) or in supporting innovation (e.g. in renewables or lower carbon vehicles). On the face of it, this argument makes sense in the context of the liberalised energy markets that have been established in many countries. Advocates of this view (e.g. Helm 2006) contend that governments should set frameworks that emphasise outcomes of policy and should leave technology choice to private investors.

A good example of this position can be found in the final report of the Interdepartmental Analysts Group that worked on the UK's 2003 energy White Paper:

> 'A prime consideration must be to create the right framework which will reward the best, most cost-effective technologies and encourage their development. This means a policy that is not about picking winners, but which allows the market to provide appropriate incentives' (Interdepartmental Analysts Group 2002).

This view is not a peculiarly British one – though it has been more prevalent in the UK than in many other countries. For example, it is a regular feature of the US policy debate (e.g. US Senate Committee on Energy and Natural Resources 2008). Some Conservative think tanks in the US argue particularly strongly that government should not get involved in technology choices[2]. Internationally, this view is also common in policy documents. The summary of a recent International Energy Agency workshop on energy technology learning and deployment concluded that 'government should avoid picking winners in the R&D and deployment stage of technologies' (International Energy Agency 2007). The European Commission's Communication on its new Strategic Energy Technology Plan makes a similar argument (European Commission 2007). However, the Commission's support for this view was contradicted by the acknowledgement that the Plan will need to be selective in the technologies it supports.

Despite its immediate attractiveness, this general reluctance to pick winners – or at least to acknowledge that this takes place – is flawed for a number of reasons. First, it would be absurd to argue that the government would like to pick losers. So by default, it is desirable that the government should set incentives that stimulate the development of future 'winners', and avoid losers as far as possible (Rip and Kemp 1998). In practice, energy innovation policies often try to do this – and favour particular technologies or sets of technologies. In the case of the UK, examples include the Renewables Obligation, capital grants for offshore wind and solar PV technologies, and the large portion of the UK R&D budget that is reserved for nuclear fusion research. Sometimes, there is tacit acceptance that some kind of prioritisation process is in operation behind the scenes (e.g. House of Commons Science and Technology Committee 2003). Occasionally, this process is more overt – for example, the UK government has made it clear that it will only provide funding for one carbon capture and storage demonstration project that uses a particular variant of carbon capture technology.

So perhaps the official rhetoric about 'not picking winners' is misplaced, and reflects an aversion to admitting that particular options have been favoured and others have not. It appears that such an admission might expose Ministers and civil servants to charges of 'failure' if these options do not become commercially successful. However, such charges would be unfair in many cases since it is not possible *a priori* to know which options will be successful and which will fail.

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[2] See, for example, opinion pieces published by the Cato Institute and Heritage Foundation.

Government Ministers, officials and advisers are often operating under uncertainty – and have a limited amount of information available to underpin choices about which technologies to back. It therefore makes sense for governments to back portfolios of technologies to maximise the chance that some will succeed.

Given the need for urgency and leadership in the response to climate change and other policy drivers, governments are less able to stay out of this messy process of trial and error. The Stern Review makes this point forcefully: 'uncertainty over the economies of scale and learning-by-doing means that some technological failures are inevitable. Technological failures can still create valuable knowledge' (Stern 2006, Chapter 16: 368). An important caveat to this is that processes need to be in place so that governments can appraise progress and, where necessary, stop supporting failing technologies before they become a drain or a distraction. Governments need sufficient independent technical expertise to inform such decisions – a capacity that has arguably declined over the two decades since the energy industries were privatised. They also require the political strength to withhold support from failing technologies – often in the face of lobbying from affected industries and 'pork barrel' politics.

A second flaw in the 'governments don't pick winners' argument is the characterisation of the public sector as incompetent. There is a deep rooted truism in many policy debates that governments are not best placed to make choices and that the market is better at making these decisions (e.g. Kammen and Margolis 1999). This does not stand up to scrutiny. The failure of government funded programmes to push favoured technologies such as supersonic passenger aircraft, synthetic transport fuels and fast breeder reactors in the absence of a market for those technologies are well documented (Borrus and Stowsky 1998; Deutch 2005). However, so are positive examples of government programmes that have led to market success (Scott and Watson 2001). Some have noted the successes of Japanese innovation support programmes (Gallagher, Holdren et al. 2006), including a long term commitment to solar PV technology that has reduced costs and supported market development (Watanabe, Wakabayashi et al. 2000). Large returns have been gained from some US government support programmes, particularly those focused on building energy efficiency and NO_x emissions reduction from power plants (National Research Council 2001). Successes also include the case of gas-fired CCGT technology which transformed many electricity industries in the 1990s. This simply would not exist without indirect state support for aircraft engines through military budgets since the Korean War (Watson 1997).

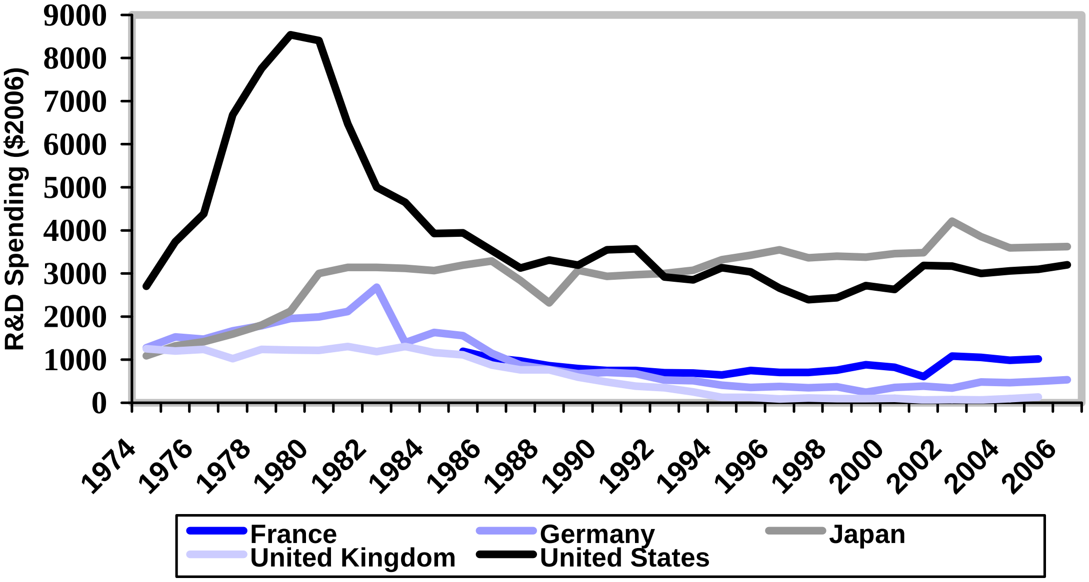
Leaving technology choice to 'the market' via generic incentive mechanisms does not mean a lack of bias in favour of particular options. In the UK, the Renewables Obligation does not differentiate between renewable technologies and has therefore favoured those that are more economically attractive and closer to market. In evidence to the House of Commons Environmental Audit Committee, the former Secretary of State for Trade and Industry Alan Johnson MP seemed perplexed by this outcome: 'We have tried not to pick winners. We have tried very hard to ensure that all these emerging technologies where we do have a natural advantage because we are an island nation have properly been explored' (Johnson 2005). This lesson does not seem to have been learned by other departments. The Department for Transport recently claimed that different low carbon vehicle technologies should receive the same level of incentive to ensure 'technology neutrality' (Department for Transport 2007).

Similarly, the market rules prevailing in many electricity markets during the 1990s meant that a large proportion of large scale investment in new generation capacity focused on gas-fired CCGTs. This was despite some political misgivings in the latter part of the decade about the desirability of this pattern of investment. As others have observed, investors are susceptible to ‘herd behaviour’ when faced with a prevailing set of incentives (Gross, Blyth et al. 2007). Whilst these investors might build some diversity into their portfolios, the aggregate effect of these private sector decisions may not be sufficient to meet overall national policy objectives.

A third flaw in this general argument is that many governments have limited resources for the support of sustainable energy technologies. Medium sized economies like the UK cannot hope to give substantive, meaningful support to all candidate options. This would remain the case even if budgets were to be increased substantially. Even the USA and Japan - the two countries that have the largest public budgets – are not thought to be spending enough on R&D to meet today’s energy challenges (Kammen and Nemet 2007). A number of studies have drawn attention to the overall decline in public energy R&D world-wide over the last 30 years (Gallagher, Holdren et al. 2006; IPCC 2007). The main exception is Japan which has consistently increased its budget over this period. As the data from the International Energy Agency in figure 1 shows, the budgets in France, Germany and the UK are a fraction of the Japanese budget – and that of the USA. Whilst this partly reflects the relative size of economies, the UK budget has been particularly small. It is much lower as a share of GDP than those of other industrialised countries (Stern 2006).

Some further observations on these trends are worth making. First, the balance of government spending within the total for each country shows some clear trends. During the 30 year period covered by figure 1, the overwhelming majority of R&D spending in these countries has focused on nuclear technologies. In France, Japan and the UK the nuclear share has exceeded 70% whilst in the USA and Germany, nuclear R&D accounted for 40% and 50% respectively. Second, the share of spending on renewable energy technologies has risen in recent years. This has reversed the declining trend in many countries during the 1990s that partly resulted from lower fossil fuel prices and a policy emphasis on the promotion of competitive markets. In 2005, R&D on renewable energy spending was the largest component of the UK budget for the first time. In some countries, fossil fuel technologies have also been supported strongly. For example, the United States has done so throughout the 1980s and 1990s with programmes to fund R&D and demonstration of cleaner coal technologies.

Figure 1. Public Energy R&D Budgets in Five G8 Countries (1974-2006)



Source: IEA Energy R&D Statistics.

A further issue with this data is that it only measures R&D supported by direct government funding for energy technologies. Funding for many transport technologies such as hybrid vehicle drive trains are excluded. The data also misses out public funding for other stages of the innovation process. For example, the IEA data does not include support from government agencies such as the Carbon Trust in the UK. In addition, it usually excludes money to support technology deployment such as the funding from consumer energy bills for renewables in Germany and the UK. Support through the UK's Renewables Obligation is expected to total some £1bn per year by 2010 (National Audit Office 2005). A more recent government report estimates that the costs of meeting the a UK target of 15% of energy from renewables by 2020 would cost £5-6bn by 2020 (Department for Business Enterprise and Regulatory Reform 2008). This figure includes substantial public provision for technology deployment.

Of course, private sector investments in energy R&D and technology development are also excluded from the IEA figures. It has been argued that private sector investments in R&D are particularly important since they are a better indicator of commercial demand for energy technologies than public R&D (Nemet 2006). It is difficult to gain a comprehensive understanding of trends in spending by energy companies. Some of this is due to patchy reporting, including different definitions of what constitutes R&D by different companies. There is also the issue of 'internationalisation'. Much of the R&D in sustainable and low carbon technologies that might benefit particular countries is undertaken by multinational or foreign firms such as oil companies (e.g. Shell), power plant equipment suppliers (e.g. General Electric) or domestic appliance manufacturers (e.g. Bosch). Despite these difficulties, the Stern Review attempted to track recent trends in private sector R&D. This showed that the oil, nuclear and utility companies have reduced their spending steadily since the late 1980s (Stern 2006). This confirms trends from the annual reports of electricity and gas utilities in the UK which show a steep decline since privatisation started in the mid 1980s (Mackerron and Watson 1996). It is also echoed in patenting data from the United States which shows that activity has fallen in line with public R&D funding of energy R&D since the early 1980s (Kammen and Margolis 1999; Nemet 2006).

Limited government budgets mean that policy makers have to work within a financial constraint even if these budgets were expanded significantly. This applies to the R&D budget itself as well as to funding via other routes for technology demonstration such as arms length government agencies and innovation support that is provided directly by consumers through their energy bills. Whilst the latter kind of support does not have implications for government budgets, issues of political acceptability still remain. For the UK, the need for prioritisation is particularly acute. Despite increases in funding in recent years, the national budget remains constrained. It is hard to see how all options – for power generation, energy efficiency, transport and energy networks – can be meaningfully supported. Yet some policy makers continue to try and square this circle. Strategy documents tend to cover all possible bases – sometimes with very modest levels of funding.

The overall implication of this line of argument is that there is a need for a clear process by which the government can make choices about which technological options should be supported. Furthermore, there is a need to debate how far processes of priority setting should go. These arguments for priority setting do not only apply to R&D, but more controversially perhaps, they can also be extended to demonstration and deployment support. The alternative – which is to support every potential technology – risks spreading resources too thinly to have any measurable impact. Furthermore, calls to ‘support all options’ also downplay the interactions, complementarities and conflicts that might occur *between* options. As the British House of Commons Science and Technology Committee argued in 2003, ‘it is reasonable to ask how the Government can have an energy RD&D policy that does not embrace a vision of which technologies should be backed’ (House of Commons Science and Technology Committee 2003). By implication, it should also have a vision for which technologies should *not* be supported to any significant extent for the time being.

4. Setting Future Priorities

Which factors should be taken into account by the government as it develops its future priorities for innovation and deployment? This section of the paper covers several important factors, some of which are already embedded in decision-making processes in many countries. Others, however, are less visible or are only partly taken into account. This section covers four important areas: the assessment and understanding of technology costs and risks, the development stage and deployment context of different technologies, the role of diversity within technology portfolios, and the extent to which industrial policy and energy policy should be integrated.

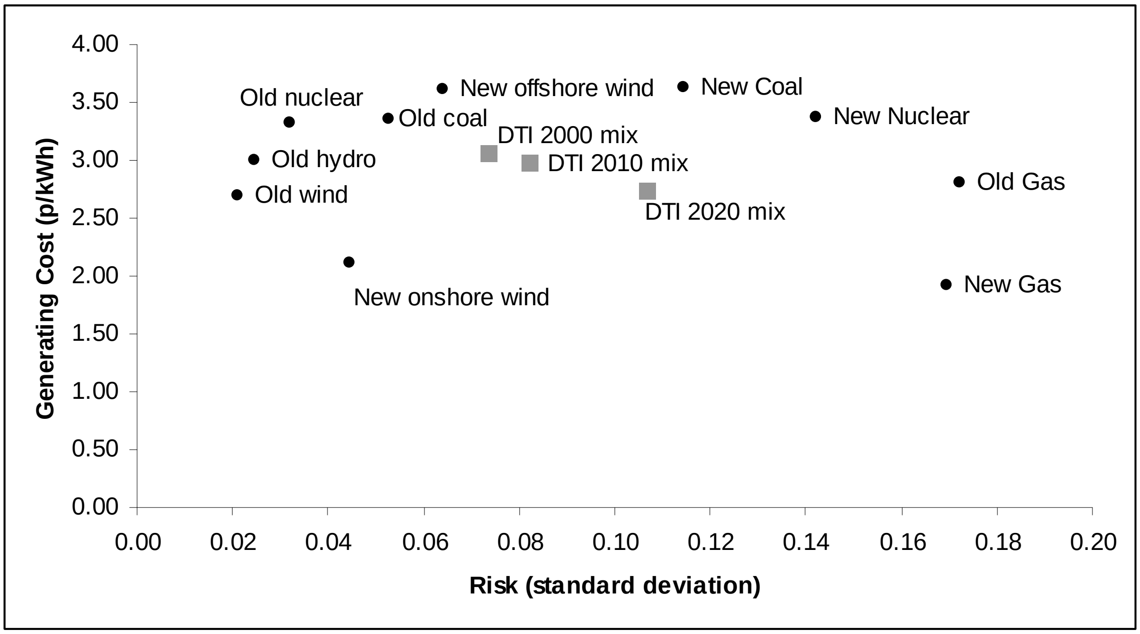
Costs and risks

A key issue for governments wishing to support the development and deployment of low carbon technologies is cost – either the current cost, or the potential future costs. These are used as a guide to understand which technologies might be the most attractive to firms and households. They also affect the type and magnitude of support that might be required to support options that are seen as desirable. Traditional approaches to the analysis of costs – particularly of alternative options for the generation of electricity – have used engineering methods. These compare the 'levelised costs' of different options in pence per kWh of electricity produced (p/kWh). Similarly, comparisons of different options to reduce carbon emissions (including demand side measures) are often compared using marginal abatement costs in £/tonne of CO_2 saved (e.g. National Audit Office 2007). The liberalisation of energy industries in many countries has made such approaches less useful. The main reason for this is the increasing involvement of private capital in electricity investments which has brought with it different perspectives on investment appraisal (Awerbuch 2003; Gross, Blyth et al. 2007).

These perspectives emphasise the understanding and management of various kinds of financial risk, for example, of capital cost increases, fossil fuel price volatility, or the absence of confidence around carbon pricing. For some financial analysts, bald figures expressed as p/kWh have little economic usefulness unless they are accompanied by a parallel comparison of risks (Awerbuch 2003). As illustrated in figure 2, Shimon Awerbuch and his colleagues demonstrated this by using some of the UK government's own cost estimates. The figure shows that technologies with similar costs (e.g. existing gas and existing wind plants) can have rather different levels of risk. Whilst the conclusion of a engineering comparison of costs using just the 'y axis' might conclude that new gas-fired technologies are cheapest, the inclusion of risk reveals that there is a trade off inherent in this particular choice. This is because other technologies such as wind benefit from having zero fuel costs (and hence zero fuel price risk) whilst gas-fired technology is penalised due to uncertainties about the future price of gas. Also factored in here are risks associated with potential capital cost uncertainties. Clearly, a more established technology such as onshore wind is characterised by a higher level of risk than offshore wind because the latter technology has a much shorter track record.

An important message for innovation policy from this insight is that different technologies might require different types or levels of support that take risks faced by private investors into account. Even if two options appear to have similar costs, incentive schemes might favour one over the other because their risk profiles differ.

Figure 2. Costs and Risks of Electricity Generating Technologies in the UK



Source: (Awerbuch, Jansen et al. 2005).

A second insight from this analysis is that different options can be combined in portfolios to hedge different risks. Figure 2 illustrates this point, using UK electricity system technology mixes in 2000, 2010 and 2020 as examples. These demonstrate the economic benefits of such mixes in terms of risk reduction. This portfolio effect is recognised widely in the private sector and leads firms to conduct R&D on an array of different technologies and to invest in a diversity of projects.

Shimon Awerbuch's work also included an analysis of this effect on the costs and risks of different future mixes of technologies (Awerbuch, Jansen et al. 2005). This used costs from the official UK government projections for the year 2003 (Department of Trade and Industry 2003) as a benchmark. For each technology within the portfolio, risk was calculated from the variability between different years of three generating cost inputs: fuel, operations and maintenance (O&M) and capital. The co-variances of these risks for the different technologies were also taken into account. Some of the results for 2010 are shown in table 1. These demonstrate that there are alternative generation mixes that contain considerably more wind energy generation than the official projections for 2010 – and that these alternative mixes cost no more.

As Shimon Awerbuch pointed out, these results should not be interpreted as confirmation that a share of 50% for wind power is feasible by 2010. The main conclusion is that 'stand-alone costs, even if adjusted for risk, do not provide a meaningful basis for evaluating energy options. Intelligent energy strategy development by necessity requires that the cost *interrelationships* of various technological options be considered … increasing the deployment of wind and other fixed-cost renewables, even if they are assumed to cost *more*, does not necessarily raise overall generating cost, as long as the generating mix can be reshuffled (re-optimized) over time (Awerbuch 2006).

Table 1. DTI 2010 Projections versus Optimized Generating Portfolios

	DTI 2010 Portfolio	**Typical Optimized Portfolios**	
		'Equal Cost'	'Equal Risk'
Portfolio Cost	2.96 p/kWh	2.96 p/kWh	2.49 p/kWh
Portfolio Risk	.08	.04	.08
Fossil Share	71%	32%	52%
Nuclear Share	16%	12%	14%
Wind Share	On-shore: 11% Offshore: 0%	On-shore: 25% Offshore: 31%	On-shore: 31% Offshore: 0%

Source: (Awerbuch, Jansen et al. 2005)

In addition to this portfolio effect, the analysis of technology costs for innovation policy also needs to take potential future cost reductions into account. It has been observed by a number of analysts that government support can help to reduce the costs of new technologies (e.g. Wene 2006). The aforementioned case of solar PV technology in Japan is a good illustration of this since costs have fallen progressively over time. Analysts have shown that many technologies have experience curves which can retrospectively describe the relationship between increasing cumulative investment and falling unit costs. This relationship is now used in some economic models that try to include technical change more fully in predictions of overall carbon abatement costs. It is also used as a rationale for some government support programmes – for example the UK's Low Carbon Buildings Programme that offers grants to individuals and organisations installing micro-generation technologies to generate electricity and heat (Department of Trade and Industry 2006).

Whilst this dynamic approach to technology costs provides important insights, it shares a shortcoming of more static approaches to these costs – the neglect of risk. Whilst there is good evidence that many technologies follow experience curves as investment in them increases, there is a tendency to discount the possibility that this might not occur (Hultman and Koomey 2007), or to assume that learning rates will be similar to rates experienced by different technologies in the past. The costs of some technologies have in fact risen over time. Two cases are particularly notable – both of which are large electricity generation technologies. Nuclear power capital costs rose in many countries during the 1970s and 1980s (MacKerron 1992). Similarly, the costs of coal-fired plants in the USA rose significantly during the 1970s (Joskow and Rose 1983). In both cases, more stringent regulation – particularly of environmental impacts – was an important factor.

Different approaches for different technologies

One important dimension of the risk profiles of different technologies is the extent to which they are commercially proven. Technologies such as the CCGT power plant or the highly efficient A++ rated fridge are established, commercially-available and well understood. By contrast, carbon capture and storage and the fuel cell hybrid car are not because they are too expensive and/or unproven. Therefore, policies to support low carbon technologies need to take their stage of development into account. For some, this would be entirely wrong (Helm 2006). Their view is that as long as carbon emissions are appropriately priced, there is no need for government to intervene further in technology deployment decisions.

The counter argument to this view is clear when the experience of energy-technology deployment is considered. The appropriate pricing of carbon emissions may be enough to encourage the uptake of technologies that are near to market. However, it is not clear what level of carbon price might be required to achieve this or whether the political process will result in policies that will deliver such a price. More importantly, such a generic incentive is unlikely to be sufficient to encourage developers of medium and long term options to develop them further so that they are available as and when required. A number of studies within the innovation literature back up this view – and have argued that policies need to take the stage of development of technologies into account as well as their context. The generic case was made in the late 1990s by Rene Kemp and others through a framework they called 'strategic niche management' (Kemp, Schot et al. 1998). This framework allows nascent technologies to be protected from normal competitive pressures for a fixed period to allow them to develop and mature, whilst fostering new networks of firms and other actors.

Specific empirical examples have been added later, for example, by Staffan Jacobsson and his colleagues. Their studies of solar PV and wind energy in Germany reveal technology-specific approaches that include R&D, demonstration programmes and market support through the feed-in tariff system (Jacobsson and Lauber 2006). Policies provided steady, tailored support to each technology as it moved from one stage of innovation to the next.

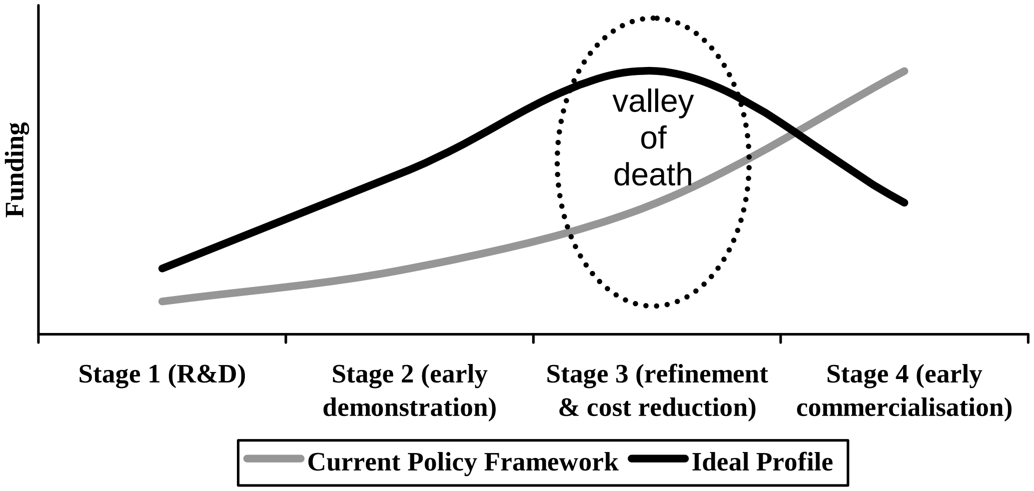
Some commentators such as the International Energy Agency have criticised the funding mechanism used in Germany to fund PV and wind deployment in Germany as 'expensive' (International Energy Agency 2007). This claim is contested (e.g. Mitchell, Bauknecht et al. 2006). It also misses the point. The fixed price feed-in tariff that is paid to developers of these technologies is not only designed to encourage cleaner electricity generation. It is also intended to stimulate innovation *and* the development of a new domestic manufacturing industry. Seen through this broader lens, the feed-in tariff is more likely to be good value for money than alternative mechanisms.

The UK's Renewables Obligation – which has been used instead of a feed-in tariff to support renewables deployment - provides a contrasting example. Whilst this policy instrument can, in theory, support a range of technologies including wind power, wave and tidal power and domestic scale photovoltaics, it has largely supported the cheapest near-market technologies. Winners under this policy include onshore wind, co-firing of biomass in conventional power plants and landfill gas (Ofgem 2007). This shortcoming has led the government to introduce 'bands' within the Renewables Obligation so that early stage technologies will receive a greater level of support – a feature that it will share with the feed-in tariff. It remains to be seen whether this will close the gap in outcomes between the successful German model and the slower progress achieved within the UK. Returning to the theme of risk for a moment, the feed-in tariff retains one key advantage – its predictable nature offers more certainty (and hence, a lower risk) to investors (e.g. Mitchell, Bauknecht et al. 2006).

This example provides important evidence that many technologies require support through several stages of the innovation process – not just initial R&D and market diffusion. The part of the innovation process that is often neglected by public policy is the stage between demonstration and commercial deployment, sometimes known as the 'valley of death' (Grubb 2005; Stern 2006, Chapter 16). The US President's Council of Advisors on Science and Technology (PCAST) stated in 1997, this 'valley of death' is due to the high costs of first-of-a-kind products … [and represents] the negative cash flow to the enterprise as the product is brought to market' (PCAST 1997, p7-14).

The Carbon Trust has argued that this gap should be addresses as part of a rebalanced profile of support for renewable energy in the UK (Carbon Trust 2006). This would reward nearer market technologies less – providing tapering support as technologies become established in the market. It would also offer greater incentives to technologies that have settled on a 'dominant design' through R&D and demonstration, but have not yet entered the early diffusion stage where costs reductions are likely to occur (see Figure 3).

Figure 3. Illustrative profiles of renewable energy funding by stage of technology development



Source: Adapted from Carbon Trust (2006).

Further evidence to support this view is provided by the experience of other, non-renewable energy technologies. For example, the US Department of Energy has spent many years supporting demonstrations of cleaner coal technologies for power generation and other applications. Whilst many of these technologies have found their way into commercial products, some of the more advanced cleaner coal options have not yet done so. Advanced options such as Integrated Gasification Combined Cycle (IGCC) are potentially important since they offer higher efficiencies than standard coal power plants. IGCC technology can also, in theory, be integrated with carbon capture and storage more efficiently and at a lower cost. Despite tax breaks and other incentives within the US Energy Policy Act of 2005, no further coal-fired IGCC plants have followed the demonstrations of the 1980s and 1990s. For many utilities, the costs and risks of new plants using IGCC and other advanced cleaner coal technologies are simply too high. Those plants that have qualified for public support under the 2005 Act have not yet received regulatory approval.

If governments accept the case for further assistance to technologies facing the 'valley of death', what kind of support would achieve this? Whilst up-front funding options such as grants, loans or tax breaks are usually used by governments for R&D and demonstration, these may be of limited use to move technologies beyond these stages. A performance incentive could be used as an alternative or complement to up-front funding. This could be a mandatory minimum performance standard (such as that being applied to European vehicle manufacturers or the approach being advocated for power plants[3]) or an incentive linked to output (such as the German feed-in tariff). This kind of incentive could be more effective in enhancing the commercial interest of technology developers in maximising efficiency, reliability and output. If the incentive were explicitly designed to minimise carbon emissions, it would also help to reinforce the rather weak carbon price signals that have been established so far.

A number of recent publications on US energy innovation policy have come out in support of this approach to policy. John Deutch, formerly a senior official in the Departments of Energy and Defence, is critical of the Energy Department's demonstration projects for coal, solar and synthetic transport fuel technologies. This has led him to advocate 'indirect incentives' (Deutch 2005) which are more in tune with commercial practices. The bipartisan National Commission on Energy Policy has also focused on performance incentives – including a specific production tax credit for power plants that are fitted with carbon capture and storage technology (National Commission on Energy Policy 2007).

Both of these publications raise another important point: performance-based incentives might also be a good way of providing public support for technology demonstrations. As the US National Commission on Energy Policy notes, a clear candidate for this is carbon capture and storage (CCS). For CCS technologies, the objective is to scale up and integrate existing component technologies, and to move towards commercial deployment (and carbon abatement) as quickly as possible. So, it may be desirable to fund both 'first of a kind' demonstrations and subsequent 'commercialisation' plants using a performance incentive linked to carbon abatement (Watson 2006).

So far, the UK and the USA have taken different approaches to funding for CCS demonstrations. Following the usual Department of Energy practice, demonstrations of CCS within the FutureGen initiative will be partly funded by up-front government grants, supported by loan guarantees (US Department of Energy 2008). By contrast, the UK demonstration of CCS has left

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[3] For example, a recent speech by the Conservative Party leader David Cameron proposed a maximum level of emissions per kWh for new power plants: Cameron, D. (2008). The choice isn't between economy and environment. Speech to environmental leaders.16th June

open the possibility that public funding could combine up-front grants and performance incentives (Department for Business Enterprise and Regulatory Reform 2007). The contrast in approach may be partly due to political factors. The US preference for up front support may partly reflect the difficulty of gaining Congressional approval for long-term technology support commitments[4]. In the UK, precedents such as the Renewables Obligation make it easier to design analogous arrangements for new technologies.

It is worth repeating here that more sustainable energy technologies will be deployed in many sectors and markets – and not just the electricity sector. As previously argued, these technologies will also be required for transport, households, buildings and industry. Given the insights of the innovation literature about the co-evolution of technologies, markets and institutions (Foxon, Kohler et al. 2008), successful innovation policies will need to take these different settings and contexts into account. This lends further weight to the view that a carbon price alone will be insufficient, even if it were equally visible, and robust, to investors such as power companies, public sector organisations and individual citizens.

Decision making processes by these investors vary widely and are constrained by different limitations and barriers. Power companies carry out detailed financial appraisals with the help of consultants. Citizens consider cost alongside many other factors – and do not make investments in energy efficiency or micro-generation in an economically 'rational' way (Watson, Sauter et al. 2006). Furthermore, their choices are often restricted by existing 'locked-in' infrastructures. For example, switching to an electric car would not just depend on whether the car itself is affordable, but also whether the infrastructure exists to charge it up. Up-front cost is a particularly important barrier to investment by householders (Oxera 2006) – something that a carbon price will do little to alleviate. Energy efficiency investments in many industries are slowed down by their own specific set of barriers (Sorrell 2004). Therefore, these different investment contexts – the home, the community, the large scale power market or the transport industry – require technology development and deployment policies that are sensitive to their particular characteristics.

How much diversity?

The advantages of diverse technology portfolios in hedging risks have already been explored in this paper. For many firms, a diverse portfolio of investments in production capacity, technology and R&D helps to manage risks. For low carbon innovation policy, the absence of perfect foresight means that it is not possible to know in advance which technologies will yield large reductions in emissions, and which ones will fail. But how far should diversity be embedded into the government's low carbon priorities?

Whilst maximising diversity sounds like an inherently good idea, there are several reasons why choices need to be made about which low carbon technologies should sensibly be supported more than others within a technology portfolio. The first of these concerns the type of diversity that is seen as desirable. In government policy documents, diversity is often associated with energy security (Department of Trade and Industry 2007: 5). Diverse routes for imported fuels (e.g. oil and gas) and diverse sources of energy (e.g. solar and biomass heating as well as gas heating in homes) are both said to be good for security. But diversity is about more than just

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[4] The stop-start nature of renewable energy production tax credits provides a good illustration of this.

having a lot of different options in an electricity generating mix or a low carbon innovation portfolio.

Andrew Stirling has identified three distinct sub-properties of diversity: variety, balance and disparity (Stirling 1998). Variety is a simple measure of the number of different options that are supported or deployed within the portfolio. Balance refers to the profile of shares of these different options within the portfolio. For example, an innovation portfolio in which one option accounts for 60% of the budget and four further options account for 10% each might be less diverse than a portfolio of five options that are allocated 20% each. Finally, disparity captures the extent to which constituent options are different from each other. An innovation portfolio that supports ten different lower carbon coal technologies is less diverse than a portfolio that supports ten renewable energy technologies. This is because the 'renewable energy' category includes many more disparate options.

Another consideration in the support of a diverse portfolio of technologies is that there is a tension between diversity and limited resources. Funding all of the available low carbon technologies from a national budget carries with it the risk that finite resources will be spread too thinly. Whilst countries with large budgets such as the USA and Japan can fund substantive programmes of support in most technology areas, countries with more modest budgets such as the UK cannot. Even if the UK's spending were to rise considerably, it would be difficult to allocate meaningful resources to all possible technologies. This is particularly the case if the portfolio is to include the considerable sums that would be required to help larger-scale technologies such as carbon capture and storage to cross the 'valley of death'.

This leads on to a further consideration. Constituent technologies within a low carbon portfolio will not be deployed in isolation from each other. Whilst some analyses appear to imply that technologies and measures are purely additive (e.g. Socolow 2005), this may not be the case. Technological options are developed and deployed within a common energy system and therefore, some interaction between options is to be expected. As noted earlier in this paper, the phenomenon of technological 'lock-in' (Unruh 2000) is important here. Technologies that do not fundamentally challenge the technical and institutional architecture of the current energy system will be easier to develop and deploy – and may dominate a portfolio if the implications are not thought through. For example, a number of studies have drawn attention to this with respect to the UK government's wish for new nuclear power construction (e.g. Mitchell and Woodman 2006). This may have knock on effects on the political and economic resources available to support other low carbon technologies. It could also limit the willingness change established infrastructures and market rules to facilitate the uptake of technologies at much smaller scales such as micro-generation or smart meters.

Common infrastructures and the technologies that underpin them are critically important here. Electricity grids, heat networks, IT infrastructure and transport infrastructures are all key components of our energy system. Their flexibility (or lack of it) will therefore enable or constrain the range of technological options and business models that can be meaningfully deployed. Road networks and petrol stations have been built for petrol and diesel cars. If policy makers wish to support alternatives that could be more sustainable (e.g. electric or hydrogen cars) new investment is required to modify these infrastructures (Department for Transport

2007). Similarly, electricity networks in most countries are optimised for centralised electricity production and one-way transmission to final users. The government also wishes to promote a more diverse mix of low carbon generation technologies, including more decentralised technologies such as solar PV, more intermittent technologies such as onshore and offshore wind, and options such as combined heat and power which maximise energy efficiency. To facilitate this, substantial innovation is required in electricity networks – something that policy has not yet engaged with seriously enough (Mitchell 2007). Innovation policy will need to be strong enough and far sighted enough to make more fundamental technical and institutional changes to these locked in infrastructures.

Energy policy as industrial policy

Senior politicians are fond of presenting climate change as an opportunity as well as a threat to the economies and societies. In September 2004, for example, former Prme Minister Tony Blair said in a speech that 'just as British know-how brought the railways and mass production to the world, so British scientists, innovators and business people can lead the world in ways to grow and develop sustainably' (Blair 2004). There is some evidence that this view is well founded, particularly if countries are early movers in implementing ambitious limits on carbon emissions. According to Michael Porter, stringent action can lead to innovation and competitive advantage through the growth of new export-led industries (Porter and van der Linde 1995). There may be an economic return from public investment in innovation that is not factored into a traditional analysis based on market failures.

Despite this high level endorsement, these arguments appear to carry little weight within some governments. In the UK, the notion that industrial policy and energy policy should be integrated is often dismissed in favour of a laissez faire attitude. Policy documents do not often express a view about the source of low carbon innovations that are deployed in the UK. The 2007 Energy White Paper has just a single paragraph about 'innovation and wealth creation' as a result of reducing carbon emissions (Department of Trade and Industry 2007: 217). This does not get into specific details about which industries that could be developed. The recent consultation on the UK renewable energy strategy goes a bit further, and points to potential strengths in resources and skills for offshore renewables (Department for Business Enterprise and Regulatory Reform 2008: p222). Similarly, the government's innovation strategy for low carbon transport makes reference to the strengths of firms based in the UK in powertrain development, lightweight vehicles and general product design (Department for Transport 2007).

Perhaps this general reticence in UK policy is related to the notion that government should not get involved in 'picking winners'. Civil servants sometimes complain in private that they would like government to offer more support to particular technologies. But their arguments that new UK-based industries could be established through this support are not taken seriously elsewhere in government.

In contrast with the situation in the UK, energy policies of other countries often place greater emphasis on this industrial policy dimension. This sees industrial development or transformation as an important outcome of energy policy, and helps firms to develop new networks, supply chains and links between users and producers. In the USA, R&D and demonstration programmes are mostly national in character, and include explicit cost sharing with 'national champion' firms to help them maintain their leadership. A good example of this is support to General Electric for advanced gas turbines (Watson 1997). In Germany, the feed-in tariff for renewable energy has been accompanied by incentives to grow new industries – e.g. in solar PV technology in Baden Wurttemberg. A recent German government policy document stated that 'research funding … helps German companies to secure top positions in the fast-growing international markets for renewable energy, and thus also creates employment … Germany's research strategy is oriented to also develop technologies which primarily find application abroad' (Federal Ministry for the Environment Nature Conservation and Nuclear Safety 2006). In France too, industrial policy has often been a central component of energy policy. The large programme of nuclear power in the 1970s and 1980s was accompanied by the growth of domestic firms such as Framatome and Cogema (these firms were subsequently merged and renamed Areva).

Even in parts of the UK with devolved governments, this dimension of energy policy has more emphasis. In Scotland, there is a particular interest in carbon capture and storage technology since this could use some established skills in offshore engineering (Scottish Enterprise 2005). These skills and Scotland's extensive renewable energy resources have also led to support for wave and tidal technologies on job creation grounds (Winskel 2007). In Wales, the low carbon economy is highlighted as one of three key priorities in the recent national science policy (Welsh Assembly Government 2006).

As these examples illustrate, the scope for industrial development as a consequence of innovation policy is substantial. But the way in which firms respond to new technology initiatives will be shaped by the success or failure of previous programmes and past investments in infrastructures (Rip and Kemp 1998). This will also depend on the broader legacy of skills, strengths and weaknesses and corporate capabilities (Magnusson, Tell et al. 2005). Bearing this in mind, it is possible to see why government policies prioritise areas in which their country has perceived strengths. Despite their reticence on industrial policy, this leads the UK government to emphasise offshore renewables and carbon capture and storage. Though it is questionable whether this emphasis has been backed up by sufficient resources.

It is important that any development of this industrial policy dimension recognises that there are limits on what national innovation policies can achieve. As mentioned previously, globalisation is pervasive in many of the industries that are developing low carbon technologies. Therefore, international collaboration by both firms and governments will continue to play an important role in innovation policy. Many countries including the UK already participate in a number of multilateral processes including the IEA technology agreements and the Framework Programmes funded by the European Commission. Bilateral and multilateral collaborations have also been pursued with many countries such as China, India and the USA. The USA itself has helped to found a number of international networks such as the Carbon Sequestration Leadership Forum and the Asia Pacific Partnership.

There are questions about the motivation for some of these organisations and the extent to which these activities will lead to tangible technological progress. However, their existence has significant implications for national policies. It is essential that policies to support innovation in low carbon technologies do so at the appropriate scale. In some cases, it will make sense for a country such as the UK to host multilateral initiatives such as demonstration projects – perhaps with participation from developing countries to help firms from those countries to build their capabilities. In other cases, encouraging firms to collaborate in projects or programmes located outside that country could help to build domestic capabilities as ‘informed buyers’ or as potential future innovators.

5. Lessons for UK Policy

So what do these various considerations mean for future policy in a country like the UK? Before discussing conclusions about the composition of innovation spending and the process of priority setting, it is important to focus on the level of budgets for energy innovation. After all, this paper argues that one of key rationales for explicit priority setting is budget constraints. This rationale is likely to remain pertinent in the UK even though the national R&D budget is now rising. Spending by government agencies such as the Carbon Trust is also increasing, as is private funding by companies and by consumers through their energy bills. The new public-private Energy Technologies Institute is another manifestation of increased resources.

Despite this turnaround in the UK, many international assessments such as the recent reports from the IPCC (IPCC 2007) and the Stern Review (Stern 2006) continue to argue that global energy R&D budgets are too low. The optimum level of increase in these budgets to deal with climate change and other energy policy challenges is the subject of some debate – particularly in the US. The President’s Council on Science and Technology Recommended in 1997 that the national budget should be doubled (PCAST 1997). Another estimate from 1999 calculated that the US energy R&D budget at the time would have to increase fourfold to act as an adequate ‘insurance policy’ against risks due to climate change, air pollution, oil price shocks and energy supply disruptions (Schock, Fulkerson et al. 1999). A more recent analysis suggests a five to ten-fold increase in US R&D would be warranted (Kammen and Nemet 2007).

This last estimate would mean an energy R&D programme of a similar size to the Manhattan or Apollo projects. Commentators – particularly in the US – are fond of making such comparisons. However, there are some serious limitations to their usefulness. First, both Apollo and Manhattan were monolithic projects. They focused on single, defined technologies to achieve very specific goals. By contrast, sustainable energy systems require the development and deployment of a wide range of technologies and products which vary in their application and scale. A second related limitation is that most sustainable energy technologies will be traded in markets which involve an array of firms, individuals and organisations as buyers and sellers. The Manhattan and Apollo projects had just one customer – the US government.

The limitations of Apollo and Manhattan analogies show that the magnitude of R&D and other funding for innovation is only part of the story. Whilst funding for basic R&D and ‘blue sky’ science and technology should be increased, there is a particularly strong case for rebalancing spending too. As this paper has noted, UK policy mechanisms that are supposed to be technology neutral such as the Renewables Obligation end up favouring those options that are nearest to market. There is little evidence that such mechanisms are sufficient to also encourage innovation in the next generation of renewable technologies. Options such as wave power, tidal power and thin film photovoltaics require more than this. Additional forms of support, for example through the Carbon Trust’s Marine Energy Accelerator, are increasingly available. In addition, the Renewables Obligation itself is being reformed with bands that provide more support to emerging technologies and less for commercialised options (Department for Business Enterprise and Regulatory Reform 2008).

One area where more resources are definitely required is in technology demonstration and the bridge between this stage and a commercial product. Supporting technologies across the infamous ‘valley of death’ is a difficult balancing act. Technologies such as carbon capture and storage (CCS), advanced electricity networks and fuel cell vehicles need such support soon so that their developers have a chance to prove them. The costs and risks will be high, but the potential rewards in terms of emissions reductions are substantial. The UK’s Environmental Transformation Fund is a significant step in the right direction, but questions remain about whether this and separate funding for a CCS demonstration are commensurate with the urgency of climate change and the maintenance of the UK’s position of political leadership.

The argument that spending needs to be rebalanced relates to another important conclusion from this paper. Energy innovation policies need to be more technology specific. How specific is open to discussion. This does not mean that government micro-management is required to the extent that each variant of low carbon or sustainable technology has a ring fenced budget. But it does mean that support programmes need to be more focused in a way that takes account of clear differences of scale and stage of development. It also means that these programmes need to take account of changes in associated infrastructure, rules and regulations that are required for new technologies to be deployed.

This change of approach has significant implications for the government’s role and for the way in which it interacts with industries and lobby groups. An end to the philosophy of technology neutrality – or at least the imposition of some limits on its use – will mean that ‘the market’ can no longer be blamed if things don’t go to plan. The government itself will be more exposed to charges that it has made the ‘wrong’ choice. Some technologies it supports will succeed whilst others will fail to deliver. What matters is that failures are dealt with rationally and are not compounded because there is a reluctance to upset vested interests. As the Stern Review notes, clear exit strategies for technology programmes are crucial (Stern 2006: 368). This does not mean, however, that market mechanisms to support innovation should be abandoned. Competitive pressures will have a vital role to play in encouraging innovation. Market support programmes can build in incentives for cost reduction – see, for example, competitions to build CCS demonstrations on both sides of the Atlantic. They can help to identify which projects within a technological category should be supported.

Another key implication of this paper is that there is a need for a more open, transparent approach to the setting of the UK’s low carbon priorities – particularly on the criteria that are used to do so. Criteria for decision making are required which include many of the factors discussed in this paper. These include current and potential future costs, risks, the diversity of different portfolios (including variety, balance and disparity), the potential for UK competitive advantage, the stage of technology development and so on. Many of these criteria are already considered in decision making. But it is difficult to tell how far this is the case, and how systematic the process is. Rhetoric about not picking winners is not helpful. It is contradicted by the existence of a range of policies in many countries that successfully give specific support to individual options or groups of technologies. It also obscures an important debate about what the priorities should be and how technologies should be supported.

There are positive signs in the development and implementation of some UK recent policies. Arguments that technology neutral policies are ‘best’ are less common, and are balanced to some extent evidence about what actually works (e.g. Department for Business Enterprise and Regulatory Reform 2008). However, it is hard to find an overarching strategy that deals with innovation across the range of more sustainable energy technologies required. Documents concerned with energy innovation policy discuss the merits of supporting one technology or set of technologies such as carbon capture and storage and renewables. This tendency to focus on electricity generation technologies has been balanced to some extent by strategies or consultations on low carbon transport, heat and power networks, energy efficiency technologies and heat – though policies to support innovation in many of these areas are lacking. Broader energy policy documents such as the 2007 Energy White Paper have emphasised the indispensability of nuclear power as a solution to climate change and energy security concerns – with little attention to the effect of this on the deployment of other options.

During the last decade, a number of more comprehensive and systematic exercises have sought to determine priorities for UK energy innovation policy. Whilst these tended to be rather closed processes, the results are publicly available. They may provide some useful pointers for future strategy. For example, the Chief Scientific Adviser set up a review group to look at energy technology priorities in the run up to the 2003 Energy White Paper. It used many of the criteria suggested here plus others to come up with a shortlist of six technology areas in which there was potential for radical technical change (Chief Scientific Adviser's Energy Research Review Group 2002). These were carbon capture and storage, energy efficiency, hydrogen production and storage, nuclear waste handling and storage, solar PV, and wave and tidal power. Going further back, the Foresight process (Martin and Irvine 1984) has also sought to put forward technological priorities through a number of panels that have covered energy technologies. According to a revealing assessment by the former head of the Parliamentary Office of Science and Technology (Euroabstracts 1998), those in Foresight were discouraged by the government from coming up with priority technologies – i.e. from ‘picking winners’. However, as panel members deliberated about the future, this is exactly what many of them wished to do.

Another desirable feature of energy innovation policies is that they should have robust evaluation and review procedures. Evaluations are currently carried out within government, though it is not clear how systematic the process is. As other authors have noted, conducting evaluations is far from simple. It is difficult to measure either the outputs (e.g. in terms of economic returns) or outcomes (in terms of successful innovations) of technology support programmes (Gallagher, Holdren et al. 2006). A combination of qualitative and quantitative criteria will need to be used to assess the broader impact of these programmes. But this does not preclude quantitative performance targets to measure progress. Such targets are often written in to US technology programmes at the start – though it is sometimes difficult to see how these are linked to the provision of funding. Adjustments to portfolios to account for the relative success or failure of different options should be made regularly. There will need to be a careful trade-off between withdrawing support when technologies show the first signs of failing to deliver and providing more patient support that acknowledges the long-term nature of many developments (Foxon

2003). But patience will need to run out at some stage – sometimes in the face of fierce opposition from potential losers.

Finally, this paper shows that the institutional arrangements for innovation policy are important. The newly established Energy Technologies Institute (ETI) in the UK might become significant for innovation and priority setting. It has a broad remit that includes transport, energy supply, demand management and fuel poverty alleviation. The Institute has already signalled three technology areas for funding – offshore wind, wave and tidal technologies, and distributed energy systems. It will need to find its place alongside a myriad of other agencies, funds and government departments that have complementary and overlapping responsibilities. The ETI's strength is that it is being run by the established energy companies that are contributing to its budget. So it can draw on their significant technological capabilities. Arguably, this strong industrial role also means that the ETI's technology priorities take commercial needs into account. Although the government is matching industrial contributions to the ETI, civil servants appear to have less influence on its strategy. But these strengths may also be weaknesses. Since more sustainable energy systems will require radical system innovations – and not just incremental innovations – incumbent energy companies may not be best placed to implement them. These companies are part of the current energy system, and therefore contribute to the 'lock in' faced by some new firms, business models and technologies.

It is interesting to note that a parallel debate on institutional arrangements is active in the United States. Some commentators have argued that a new 'arms length' agency should also be set up there. This would compensate for the perceived weaknesses of Federal government support programmes and help to bypass the technology 'pork barrel' that has a large influence on what is funded. A focus of debate has been the merits of an 'ARPA E' agency which would build on the experience of DARPA[5], an agency which was set up to develop military technologies. DARPA has been particularly successful at supporting technologies across the 'valley of death' (Bonvillian 2007). However, it has been rightly argued that such a monolithic model would not be appropriate for energy (Bonvillian 2007). Whilst DARPA has a single important customer (the US government), energy technologies need to be commercialised and sold to individuals and companies in private markets (Mowery 2006). One alternative put forward by John Deutch is a new independent Energy Technology Corporation to fund demonstration projects (Deutch 2005) – a proposal rather similar to the ETI.

It remains to be seen whether the foundation of the ETI and the general expansion of innovation funding in the UK will help to address the need for a more strategic approach to energy innovation policy. Any move towards more explicit priority setting will be fraught with difficulties. Selecting appropriate criteria for assessment and funding, coping with limited foresight, and dealing with the risks of backing the 'wrong' options are just some of the challenges that will arise. It is also inevitable that there will be disagreements over both process and outcomes. As the government itself acknowledges in its energy policy documents, there is more than one way to meet our energy and climate policy goals.

Nevertheless it is hard to see how government can avoid prioritising particular technologies over others. Climate change is real. Time is short. Even though budgets are being increased, they are

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[5] The Defence Advanced Research Projects Agency was set up by President Eisenhower in 1957.

limited. It is crucial that the choices that are made recognise the ‘locked in’ intertia of incumbent energy infrastructures and their associated policies and institutions. The corollary of this is the need to make space for the more radical innovations for system change that are likely to be required. Given these realities, a more transparent approach will help to ensure that the actions that are taken are open to scrutiny. More important, it will promote learning about what works, and help to ensure that failures do not turn into public policy disasters.

Acknowledgements

I would like to thank Ivan Scrase and Mike Parker of the Sussex Energy Group, David Vincent of the Carbon Trust, Kelly Sims Gallagher and Laura Diaz Anadon of the Kennedy School of Government, Harvard University and Greg Nemet of the University of Wisconsin-Madison for valuable comments on previous drafts of this paper. I’m also grateful for financial support from the ESRC through its funding for the Sussex Energy Group. An earlier version of this paper was originally planned as a joint effort with my late and much missed colleague Shimon Awerbuch. This paper is dedicated to him.

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