Energy Technology Innovation: A Systems Perspective

Report for the Garnaut Climate Change Review

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Executive Summary

The Garnaut Review will emphasise innovation in new energy technologies and processes as a key element in the delivery of deep cuts in carbon emissions. Consequently, it matters to understand both drivers for and barriers to innovation in the stationary energy sector which accounts for 50% of Australia's greenhouse gas emissions. This report:

- Articulates a theoretical framework for the assessment of relevant innovation systems, to assist in the identification of innovation barriers, market failures and gaps, relating to research, development, deployment and commercialisation of new low carbon energy technologies and processes.
- Analyses key factors relating to investment decisions in energy sectors.
- Provides broad principles for energy technology innovation policy, and outlines how these might be applied in the Australian context.

Our review of innovation systems theory supports the finding of the Stern Review that, *in addition* to putting a market price on carbon emissions, complementary measures are needed to promote low carbon innovation directly. This report focuses on the rationale and potential measures in an Australian context.

Section 1 synthesises current theories of innovation systems and processes. These theories emphasise: the systemic interactions and feedbacks between a range of 'actors', including firms, entrepreneurs, consumers, policy makers and regulatory agencies; the importance of learning processes and the future expectations of these actors, operating in an environment of risks and uncertainties; and the role of the institutional framework of rules, incentives and 'routines' in influencing their expectations and current behaviour.

These theories highlight the role of positive feedbacks to the adoption of technologies and associated rule-systems. Section 2 argues that feedbacks of this kind have led to a current state of 'carbon lock-in', creating barriers to the innovation and deployment of low carbon technologies. Current fossil fuel based systems have been successful in meeting consumer demands for energy, transport and heat services at relatively low private costs, but to the neglect of some potentially serious environmental and social costs.

This report argues that, in order to overcome this state of carbon lock-in, direct support for innovation at two levels is needed to complement measures to put a price on carbon emissions. Carbon pricing will be crucial for the achievement of a low carbon economy, but it is best suited for mature low carbon technologies and needs to be complemented by measures to promote innovation and commercialisation of low carbon technologies currently at earlier stages of development. Firstly, it matters to set a long-term, stable and consistent strategic framework to promote a transition to a low carbon economy. This would help to create a positive climate for investment in a diverse range of low carbon technologies. The key aim is to ensure that steps towards achieving long-term systemic changes in technological systems are put in place alongside measures to deliver emissions reductions in the short and medium term. The second form of support involves measures to support innovation, which could include:

- Tax or other incentives for private R&D, combined with finance for public R&D in public research institutions and universities;

- Tax incentives and/or grant finance for demonstration projects;
- Public procurement of innovative technologies—such as solar roofs and micro-generators for public buildings, fuel cells for the defence and aerospace industries and for demonstrator buses, and so forth;
- Regulatory incentives and standards for low carbon technologies (low carbon vehicles for example, and efficiency standards in buildings and for a large number of appliances);
- Price support mechanisms or obligations again for innovative technologies in their early phases of development;
- Tax credits for investment in or the use of innovative technologies.

In order to assess the appropriate mix of policies, more detailed analyses of innovation systems are required, which are not undertaken in this report. However, Section 3 presents a framework for assessing energy innovation systems, in order to identify innovation barriers, market failures and gaps, based on previous work for the UK Department of Trade and Industry, on UK renewables innovation systems. This work combined innovation systems thinking with the 'innovation chain' picture to help identify policies that would be appropriate for technologies at different stages of development. This framework enables the identification of 'systems failures' in bringing early stage technologies along the innovation chain towards commercialisation, and potential policy measures to address these failures.

Under conditions of energy market liberalisation and private sector ownership, such policies will only work if they provide a climate that is favourable to investment. In part, this is a product of financial support and/or the removal of barriers to development. Investment risk is also affected by a range of other factors, however, and Section 4 introduces some key issues related to policy, investment and risk, based upon a recent report for the UK Energy Research Centre (UKERC).

Under liberalised markets, investment is driven by expected returns, which investors assess in the light of a range of risks related to both costs and *revenues*. An important category of revenue risks is associated with electricity price fluctuations. This report argues that there is a *'risk hierarchy'* linking policy to technology maturity:

- *Capital subsidies and/or Private Finance Initiative equity stakes are most likely to be appropriate for wholly new technologies emerging from R&D*, and/or for unproven and large scale 'lumpy' investments where there is limited prospect of incremental learning through small scale early commercial units, e.g. Carbon Capture and Storage (CCS) and possibly wave power.
- *Revenue support is important, but there are choices in design that affect how risk is allocated*
    - *Fixed price tariff schemes (feed in tariffs) may be most appropriate for development and deployment of emerging technologies;* i.e. those demonstrated, but yet to be used on a large scale, that are subject to considerable technology risk and have yet to benefit from extensive 'learning by using', e.g. offshore wind and possibly CCS.
    - *Market based schemes (tradable obligations) are generally most suited to proven technologies*, or to incentivise least cost means for short term carbon reduction, e.g. onshore wind.

- *Policies designed to support investment in high risk, early stage options will be most effective if in addition to providing remuneration they also seek to reduce or remove revenue risks associated with price volatility.* Very early stage options may benefit from capital subsidies that can also mitigate technology risks.

Once again, these can be seen as complements for carbon pricing, which can provide the long term incentives for continued deployment and development as the technologies mature, as well providing an additional incentive for innovation.

Finally, Section 5 briefly reviews the context of Australian energy technology innovation systems. The innovation systems approach suggests that future research could focus on the following key issues:

- ***Options for providing a long term framework to promote a transition to low carbon energy***: A long-term framework of clear and credible goals and targets can provide important signals to investor expectations, and help to inform the establishment of a coherent and effective mix of policies to promote innovation directly alongside policies to price carbon emissions, whether through trading schemes or taxation.

- ***Options to provide financial support for demonstration and commercial scale roll out of carbon capture and storage (CCS)***: Mechanisms for commercial scale CCS development are yet to be analysed in detail anywhere in the world. If the Australian government wishes to take a lead in the development of CCS then the risks imposed by electricity markets need to be factored into an investment focused analysis that considers a wide range of policy options including grants, obligations and feed in tariffs.

- ***Policies to encourage the development of large scale renewables***: Should a decision to expand or revise the MRET be taken it is also important for the government to assess the nature and diversity of technologies it wishes to support, and the most effective mechanism for promoting such diversity. The predominance of feed in tariffs in countries that have expanded their renewables industries, and the problems for investors created by tradable certificate schemes such as the RO/MRET, are well documented.

- ***Policies to promote PV:*** The potential importance of solar power is already reflected in Australian policies. Expanded utilisation will require additional measures. Experience from around the world indicates that small scale investors face particular barriers, and policies need to be targeted towards these. Successful support schemes for small scale PV use a mix of capital subsidies and fixed price payments for output. Transaction costs and complexities represent a considerable barrier to householders or small businesses accessing markets for renewable certificates.

- ***Policies to facilitate infrastructural investment***: These deserve particular attention in Australia because of the potentially large distances involved in terms of electricity transmission and CO2 transport.

Contents

Introduction

This report provides a contribution to the Garnaut Climate Change Review, an independent study by Professor Ross Garnaut, commissioned by Australia's State and Territory Governments on 30 April 2007. The recently elected Prime Minister of Australia has confirmed the participation of the Commonwealth Government in the Review. The Garnaut Review will examine the impacts of climate change on the Australian economy and recommend medium to long-term policies to achieve sustainable prosperity.

The Garnaut Review will emphasise technological innovation as a key to delivering deep cuts in carbon emissions, whilst protecting and enhancing Australia’s national competitiveness. This report will provide a theoretical framework for identifying, analysing and discussing barriers to innovation in the key carbon intensive sector of energy generation, based on a synthesis of the innovation literature on energy technologies.

It is there important to gain an understanding of the drivers for, and barriers to, innovation in the energy sector. This report seeks to:

- Articulate a theoretical framework for assessing relevant innovation systems, in order to enable identification of innovation barriers, market failures and gaps, relating to research, development, deployment and commercialisation of new low carbon goods and services.
- Analyse key factors relating to investment decisions in energy sectors.
- Provide broad principles for energy technology innovation policy, and outline how these may be applied in the Australian context.

The report has five main sections. Section 1 provides a synthesis of current theories of innovation systems and processes. Section 2 applies these ideas to low carbon innovation policy, identifying the challenges associated with overcoming the current state of ‘carbon lock-in’ and potential policy measures to address these. Section 3 sets out a theoretical framework for identifying barriers, failures and gaps within energy technology innovation systems. This serves to identify ‘systems failures’ within current energy innovation systems, drawing out generic policy implications. The detailed application of this framework to Australian innovation systems is beyond the scope of this report, but will be taken up within the Garnaut Review. Section 4 explores in more detail key factors relating to investment decisions in the face of uncertainty and risk. Section 5 draws out further questions and areas for research in the application of innovation policy to the task of promoting energy technology innovation in Australia. Section 6 provides some concluding remarks, drawing together the various strands in the report.

1 Synthesis of current theories of innovation systems and processes

This section reviews recent academic and policy-relevant literature examining a systems approach to innovation. It builds on previous work for the UK Carbon Trust (Foxon 2003), developed to take into account recent additions to the literature. It covers:

- **Broad conceptual models of innovation;**
- **Aspects of innovation process, including learning curves, technological trajectories, life cycle and dominant design;**
- **OECD's work on National Innovation Systems;**
- **Recent work on technological innovation systems.**

Three key themes emerge from these innovation systems approaches: (1) systematic interactions between firms, networks and institutions; (2) the role of learning and future expectations; (3) the influence of institutional frameworks on the rate and direction of technological innovation.

1.1 A brief history of innovation

Though classical economists from Adam Smith to Karl Marx were very much concerned with issues relating to technological and institutional change, the first systematic attempt by an economist to understand the processes of innovation was the work of Schumpeter (1911) in the first half of the twentieth century. He identified three stages of the innovation process – *invention*, *innovation* and *diffusion* – a classification still widely used, though now being challenged as over-simplistic. He identified *invention* as the first practical demonstration of an idea; *innovation* as the first commercial application of an invention in the market; and *diffusion* as the spreading of the technology or process throughout the market.

The classical representation of the diffusion process is by an S-shaped curve, in which the take-up of the new technology begins slowly, then 'takes off' and achieves a period of rapid diffusion, before gradually slowing down as market saturation levels are reached. Schumpeter's metaphor of '*creative destruction*' to describe the process of the replacement of old firms and old products by innovative new firms and products has also been widely influential, both in the popular conception of capitalism and in inspiring more recent understanding of the process of innovation.

This three-stage classification underlies what is often referred to as the 'linear model of innovation'. This describes innovation as a process of more-or-less continuous flow through the three stages, from basic research to applied research to technology development and diffusion. This was reflected in the post-war optimism of the influential U.S. report by Vannevar Bush (1945) called 'Science: The Endless Frontier', stating that "basic research provides the fund from which the practical applications of knowledge must be drawn". This view can be taken to imply that the best way to increase the output of useful new technologies is to increase the input of new inventions by putting more resources into R&D. This is the process of *technology-* or *supply-push*. The alternative perspective, that demand for products and services is more important in stimulating inventive activity than advances in the state of knowledge, so-called *demand-pull*, was first put forward by the work of Zvi Griliches (1957) and Jacob Schmookler (1966).

More recent theoretical approaches accept the roles of both technology-push and demand-pull, but stress the importance of feedbacks between the supply and demand sides. Crucially, *innovation* can be thought of as the process of matching technical possibilities to market opportunities, through activities including experimental development and design, trial production and marketing (Freeman & Soete 1997).

Contributions by economists

The work of Robert Solow and others, in which they investigated the relative importance of different factors to the economic growth rates of national economies, drew attention to the macro-economic importance of understanding innovation and its consequences. Solow (1957) used a standard economic production function to estimate that the largest contribution to growth did not come from increases in labour or capital productivity, but from a residual which he identified broadly as *technical change*. His original estimate was that over 80% of growth was due to technical change. Subsequent clarifications, which included *inter alia* adjustments for the education and ‘quality’ of the labour force, argued that about two fifths of the total increase in US national income per head was due to technological change, i.e. advances in knowledge resulting in economic applications, see Stoneman (1995).

Applying the linear model of innovation, it was asked whether the level of investment in research and development (R&D) was sufficient to meet national economic needs. Richard Nelson (1959) and Kenneth Arrow (1962a) employing neo-classical economic principles, argued that the social returns to research investment exceed the private returns made by the individual firm. The firm can not *appropriate* all the fruits of its investment because advances in knowledge ‘spill over’ in ‘external benefits’ to other firms and consumers. This argument makes a case for the public support of basic scientific and technological research, in pursuit of what the economics literature terms a ‘public good’. Again, much work has been undertaken to clarify the conditions under which such public support could be most effective and efficient. Arrow (1962a) identified the problem of ‘moral hazard’ – that the shifting of risks, and potential gains, from the private to the public sector may further reduce the incentives for private investment in R&D. Nevertheless, the basic principle of public investment in R&D has been accepted and applied in most industrialised countries.

The problem of the appropriability of private investment in R&D long ago gave rise to another policy instrument designed to induce invention and innovation by protecting the innovator’s *property rights* – the *patent*. For example, in the eighteenth century, patents were aggressively exploited by James Watt and his partner Matthew Boulton to protect their interests in improvements in steam technologies. Remarkably, the right to patent is embodied in the US Constitution: “The Congress shall have the power … to promote the progress of science and the useful arts, by securing for limited times to authors and inventors the exclusive rights to the respective writings and discoveries.” As this makes clear, a patent provides a temporary monopoly for the first person to invent and describe a new product or process. To be patentable, an invention must be novel, non-obvious and useful.

1.2 Broad conceptual models for understanding technological change

Vernon Ruttan, in his excellent review of the current theoretical and empirical state of play (Ruttan 2001), identifies three broad approaches to understanding technological change and innovation – *induced innovation, evolutionary approaches,* and *path-dependent models*. He argues that these three models represent complementary elements of a yet to be developed more general theory. Other useful recent reviews of technological innovation in relation to environmental policy may be found in Kemp (1997), Grubler (1998), Jaffe et al. (2003) and Grubb (2004).

(1) Induced innovation

Induced innovation approaches emphasise market drivers and analyse the impact of changes in the economic environment on the rate and direction of technical change. The importance of demand pull mechanisms has already been mentioned. Another key insight dates back to neo-classical economist John Hicks (1932) – that a change in the relative prices of factors of production is itself a spur to innovation directed at economising the use of the factor that has become relatively expensive. This implies that if, for example, labour becomes relatively more expensive compared to capital, say because of labour shortages, innovation will be directed towards more labour-saving technologies, of which there are many examples in agriculture, industry and economic services.

(2) Evolutionary theory

The modern approach to an evolutionary theory of technical change was pioneered by Richard Nelson and Sidney Winter (Nelson & Winter 1982). Their approach builds on two foundations - the Schumpeterian understanding of innovation, and the idea of 'bounded rationality', first put forward by Herbert Simon. Simon (1955) noted that decision makers, either individuals or firms, are limited in their ability to gather and process information and so, rather than being perfectly rational profit-maximisers, they make decisions that satisfy whatever are their most important criteria, i.e. they '*satisfice*' rather than optimise[1].

Nelson and Winter jettison much of what they consider to be the 'excess baggage' of the neoclassical microeconomic model, including the existence of a well-defined choice set, perfect foresight and the profit-maximising assumption. Instead, they replace the production function of the firm by the concept of *'routine'*, defined as any technical, procedural, organisational or strategic process or technique used by a firm as part of its normal business activities, for example, its R&D strategy. Routines change by a process of *searching* for better techniques. Successful routines, and firms that employ them, are then *selected* by processes of market competition. Using simulation models, Nelson and Winter investigated the behaviour of firms under these assumptions to show how the ability of firms to capture economic rents, in markets which are not perfectly competitive, influences the rate and direction of technical change. Their models show how innovation and imitation can arise without a profit-

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[1] The counter-argument by Milton Friedman (1953) that real firms behave 'as if' they are profit-maximisers, because only those firms will survive market competition, assumes the existence of perfectly competitive markets, which is highly unlikely in the face of rapid technological change, imperfect information and environmental and other externalities

maximising assumption, but can reproduce the results of neo-classical models, e.g. that a higher wage rate will tend to increase capital intensity.

(3) Path dependent models

'Path dependency' in this context is the idea that the successful innovation and take up of a new technology depends on the path of its development, including the particular characteristics of initial markets, the institutional and regulatory factors governing its introduction and the expectations of consumers. Arthur (1994) examined the importance of 'increasing returns' to adoption, i.e. positive feedbacks which mean that the more a technology is adopted, the more likely it is for its costs per unit to fall and for it to be further adopted.

He identified four major classes of increasing returns: *scale economies; learning effects; adaptive expectations* and *network economies*. *Economies of scale* reflect the fact that for some technologies unit costs decline as fixed costs are spread over increasing production volumes; and falling costs encourage demand to increase. *Learning effects* reflect product improvements and cost declines as experience is gained in the production and application of a technology. (In important respects therefore Arthur's work links to Arrow's work on learning-by-doing, described below.) *Adaptive expectations* arise as increasing adoption reduces uncertainty and both users and producers become increasingly confident about quality, performance and longevity of the current technology. *Network* or *co-ordination effects* occur for technologies for which the more users there are, the more useful the technology becomes, such as for mobile phones or fax machines.

Box 1.1: Historical Illustrations of Lock-in

Arthur (1989) showed that, in a simple model of two competing technologies, these effects can amplify small, essentially random, initial variations in market share, resulting in one technology achieving complete market dominance at the expense of the other, a situation he called technological 'lock-in'. He speculated that, once lock-in is achieved, this can prevent the take up of potentially superior alternatives.

A series of historical studies reinforced arguments for path dependency, by showing how lock-in has occurred in a variety of cases, including:

- The QWERTY keyboard layout, which was originally designed to reduce the frequency of mechanical failures in early typewriters around the late 1800s (David, 1985); and
- The 'light water' nuclear reactor design, which was originally designed for submarine propulsion, but, following political pressure for rapid peaceful use of nuclear technology, was adopted for the first nuclear power stations and rapidly became the standard design in the U.S. (Cowan 1990).

Specific historical examples of path dependency have been criticised, particularly QWERTY (Liebowitz & Margolis 1995), as has the failure to explain how 'lock-in' is eventually broken, but the plausibility of these ideas has been widely accepted.

Further work in this approach applied these ideas to the development of institutions, defined as "the social rules that facilitate co-ordination among people by helping them form expectations for dealing with each other" (Ruttan 2001). This broad definition of institutions encompasses forms of property rights, rules governing market behaviour such as contracts, and non-market forms of co-ordination between actors, such as sharing of knowledge and agreement on technical standards. The role of the institutional set-up within a nation, and increasingly at an international level, is crucial to providing incentives and opportunities for technological innovation.

North (1990) argued that similar types of increasing returns to those identified by Arthur for technological change also apply to institutions, so that the more an institutional rule or framework is applied, the more stable it becomes. New institutions often entail *high set-up or fixed costs*, so there are opportunities for economies of scale; significant *learning effects* arise because of the opportunities provided by the institutional framework; *co-ordination effects* occur via formal contracts and informal interactions between organisations; and *adaptive expectations* occur because evidence of the survival of a specific institutional framework reduces uncertainty about the continuation of that framework. In summary, North argues, "the interdependent web of an institutional matrix produces massive increasing returns."

Pierson (2000) argued that *political* institutions are particularly prone to these types of increasing returns, because of four factors: the central role of *collective action*; the *high density* of institutions; the possibilities for using political authority to enhance *asymmetries of power*; and the *complexity and opacity* of politics. The key point here is that when actors are in a position to impose rules on others, they may use this authority to prevent changes in the rules (both formal institutions and public policies) which would diminish their own power. In Section 2.1, the implications of this for the reinforcement of rule systems supporting current energy technologies is considered.

Towards a more general theory

The evolutionary and path dependency approaches emphasise the extent to which past decisions, embodied in technologies and institutions, can constrain present innovation, whilst the induced innovation perspective stresses the long-run importance of changes in relative prices in driving the direction of technical change. As Ruttan (2001) argues, the complementarity of these positions suggests that they could well be elements of a more general theory of innovation, which has yet to be produced. Aspects of these three models of innovation– induced, evolutionary and path dependent, have appeared in more recent approaches which take a systems perspective, which are reviewed in Sections 1.4 and 1.5.

1.3 Understanding the process of innovation

This section examines the more detailed concepts and 'stylised facts' gleaned from empirical studies which are used to help understand technological innovation. These begin to establish the links between technological and institutional innovation, which are developed more fully in the systems approaches described below.

Types of learning

In different ways, the three approaches to technological innovation, described in Section 1.1, all stress the role of learning as a key part of the innovation process. At least three ways by which learning occurs have been identified: *learning-by-doing*, *learning-by-using* and *learning-by-interacting*.

(1) Learning-by-doing

The importance of 'learning-by-doing', that as experience in their production is gained the quality of products improves and their cost decreases, was first noted by engineers working in manufacturing industries such as aircraft and shipbuilding. This idea was formalised in a famous paper by Kenneth Arrow (Arrow 1962b). In Arrow's model, the productivity of a firm increases as the cumulative output for the industry grows. Increasing returns, i.e. positive feedbacks, arise because knowledge discovered in the processes of investment and production enables improvements in production efficiency. This generates both private benefit for the firm and positive externalities, i.e. wider benefits to society, because the new knowledge becomes public knowledge.

(2) Learning-by-using

Building on a series of historical case studies, Rosenberg (1982) identified a second locus of learning, 'learning-by-using', i.e. gains in knowledge generated as a result of subsequent use of the product or technology. Focussing in particular on capital goods, Rosenberg showed that many potential gains in efficiency can only be identified through the experience gained in the use of the product by the consumer. He argued that this process would be particularly relevant for long-lived durable goods or for goods that form part of more complex technological systems. For such goods, their precise performance in real environments, as opposed to under controlled conditions, is uncertain, and feedback from actual use is necessary to be able to improve this performance.

(3) Learning-by-interacting

Lundvall (1992) argued that 'learning-by-interacting', i.e. learning as a result of interactions between producers and users, is mediated not merely by price mechanisms, but also by closer interactions involving mutual trust and mutually respected codes of behaviour. In particular, when difficulties or bottlenecks occur in technological systems, if appropriate lines of communication exist or develop between the needs of users and the capabilities of producers, then they may effect mutually beneficial learning, giving rise to process or product innovations.

These three types of learning have in common that they occur within the current *technological system* or *regime* (see below for further explanation), generally giving rise to incremental innovation. However, recent thinking argues that most *radical innovations* develop from *niches* outside the current dominant regime, as discussed below.

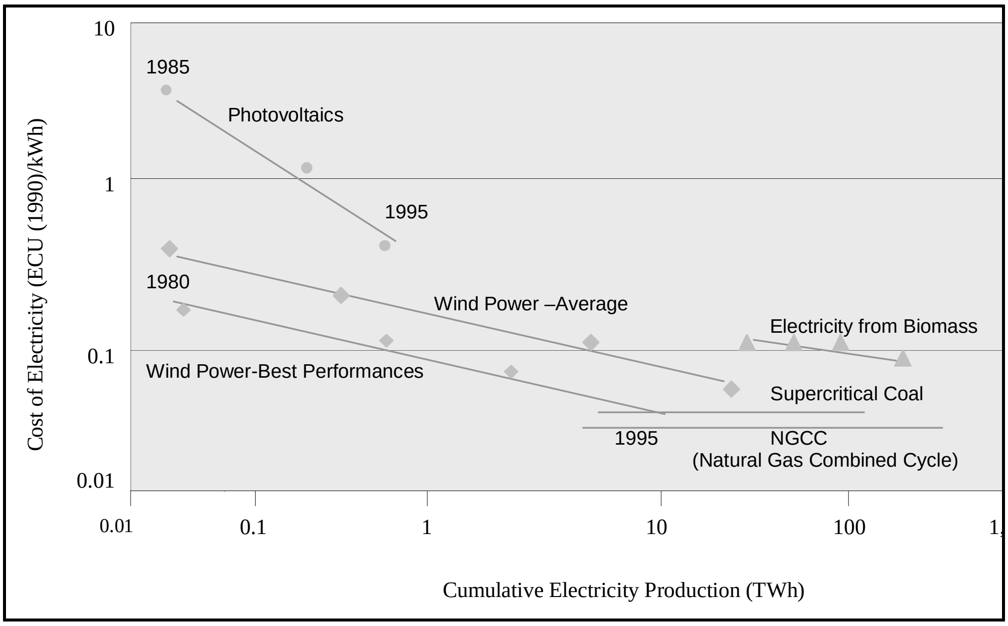
Box 1.2: Learning Curves

The economic effects of the three types of learning are represented in the analysis of *learning* or *experience curves* (IEA 2000) which show empirically the reduction of unit costs of a technology with cumulative production.

For technologies in the early stages of development, learning rates of 10 to 20% are observed, i.e. unit costs fall by 10 to 20% with a doubling in cumulative installation (McDonald & Schrattenholzer 2001; Junginger et al. 2005).

Technologies in the early stages of development typically have significantly higher unit costs than the established alternatives. Learning curves can be used to estimate the amount of deployment support needed to bring the cost of a new technology down to the level at which it is competitive with the existing technology under a carbon price, as shown in the figure below. The implications of learning curves for technology policy are discussed in Section 2.3.

Learning Curve Data for Selected Energy Technologies (IEA 2000)



Technological trajectories, regimes and paradigms

Closely related to the role of learning is the idea that knowledge accumulates over time, and that the current state knowledge influences the directions in which new knowledge is searched for. Within the evolutionary approach, Nelson & Winter (1977) identify firms doing R&D as engaged in a process of searching for solutions, guided by a combination of knowledge of technological capabilities (supply-push) and user needs (demand-pull), generating a variety of possibilities. These possibilities are tested in a ‘selection environment’, which consists of both market and non-market elements. The latter arise from the institutional structures in place, for example, regulations, codes of behaviour, non-profit making bodies. The accepted or prevailing set of technologies and institutions form a technological *regime*. This acts to guide the search process along particular *trajectories*, which in general favour incremental innovations to current products or processes.

This idea was developed by Dosi (1982), who pictured technological trajectories being the result of 'normal' problem solving activities within the prevailing technological regime or *paradigm*, which defines the relevant economic and technological trade-offs. This idea is closely related to the path dependency approach, in which increasing returns to technological adoption reinforce particular paths of development. Hence, "dynamic increasing returns tend to 'lock in' the processes of technical change into particular trajectories, entailing a mutual reinforcement between a certain pattern of learning and a pattern of allocation of resources into innovative activities where learning has already occurred in the past" (Dosi 1988).

This picture of the cumulative nature of the innovation process stresses the importance of learning and the role of the knowledge base, which is built up by investment in R&D. Although the role of market factors and relative prices is clearly important in inducing innovation, "economic incentives to reduce costs always exist in business operations, and precisely because such incentives are so diffuse and general, they do not explain very much in terms of the *particular sequence and timing of innovative activity*" (Rosenberg 1976). Dosi (1988) argued that "specific incentives, *coupled with the paradigm-bound, cumulative, and local nature of technological learning* can explain particular rates and directions of technological advance".

Life cycle and dominant design

As a result of this cumulative nature of the innovation process, empirical evidence suggests that technologies exhibit a 'life cycle' of development (Nelson 1994). In the early stages of development of a new technology, there are a variety of possible designs competing for acceptance. Because of particular advantageous features of a certain design, which may make it especially suited to a particular niche market, that design will begin to be taken up. However, the institutional set-up will still in general be adapted to the existing technological system, effectively creating a barrier to the take up of the new technology. Only if conditions enable the new technological design to undergo sufficient learning within in its early niche markets, through a combination of learning-by-doing, learning-by-using and learning-by-interacting, can it improve performance and reduce unit cost, thereby generating increasing returns to adoption. Thus, sufficient institutional flexibility to enable these types of learning to occur is essential.

As the market for the new technology grows, at the expense of the current technology, institutional change gradually occurs, as the institutional set-up adapts to match the needs of the new technology. For the new institutional framework to develop, it needs to similarly generate its own set of increasing returns, and, if the institutional inertia is strong, it can delay or prevent the adoption of the new technology. If the combination of improved technological capability matching user needs, together with adapted institutional framework, is compelling, then the new technology spreads rapidly until it achieves the status of a '*dominant design*' (Utterbach 1994). From then on, only incremental improvements will then occur to the design, as it has become institutionally embedded.

As well as the essential nurturing role of niche markets, much interest has focussed on how industry structure is related to the potential for radical innovations. Though large firms are more likely to have the R&D capacity to generate potential new ideas, this activity will typically be focussed on incremental improvements along the existing technological trajectory. Smaller firms, which may not have capital and skills invested in the old technological system, will be more likely to invest in the riskier development of more radical approaches, providing that they can draw on venture capital, scientific research and fundamental skills. Thus, the typical pattern for a radical innovation is for it to be developed by small firms in a niche, which then grows and eventually displaces the current dominant design technology. Often, the firms which are the market leaders in the current technologies are unable to adapt and face severe difficulties (Christensen 1997). This process has been called 'disruptive innovation'

Christensen (1997) considered in detail different generations of computer disk drives. He showed that each subsequent generation was developed by firms outside the current mainstream, and initially employed in a niche, which grew and displaced the current market-leading technology and firms.

This understanding is now feeding back into the behaviour of large firms. They sometimes set up semi-autonomous divisions or spin-out companies to research and develop more radical innovations. This is important because the incentive structure and risk profile for radical innovation is different from that for incremental innovation. The likelihood of initial failure is higher, the need for learning is greater, but the potential is higher for generating breakthroughs which will have significant impact on the company's long-term profitability.

1.4 Innovation systems

Many of the above ideas are brought together in recent work on innovation systems. This work on two types of system: *national innovation systems*, looking at the overall incentives for innovation within particular countries, and *technological innovation systems*, looking at incentives for innovation in relation to particular technologies, either within a country or at a global level.

National Innovation Systems

The concept of a national system of innovation was first developed by Chris Freeman, working at the Science Policy Research Unit (SPRU) at the University of Sussex. Freeman (1988) defined a *national system of innovation* as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies." In a pioneering study of the successful Japanese economy in the late 1980s, he stressed the positive role of government, working closely with industry and the science base, to create a *vision* and provide *long-term support* for the development and marketing of the most advanced technologies; the *integrated approach* to R&D, design, procurement, production and marketing within large firms; and the high level of general *education* and scientific culture, combined with thorough practical *training* and frequent up-dating in industry.

Lundvall (1992) and Nelson (1993), in two major studies in the early 1990s, analysed national innovation systems in more detail. Lundvall (1992) defined a national system of innovation as constituted by "the elements and relationships which *interact* in the production, diffusion and use of new, and economically useful, knowledge … either located within or rooted inside the borders of a nation state." He stressed the role of interactions between *users* and *producers*, facilitating a flow of information and knowledge linking technological capabilities to user needs. Because of the fundamental *uncertainty* of innovation, these interactions go beyond pure market mechanisms, and rely on mutual trust and mutually respected codes of behaviour.

In this picture, innovation is seen as a process which is *ubiquitous* and *cumulative*, involving new combinations of knowledge, produced through various forms of *learning*, as described in Section 1.4. Even activities aimed specifically at contributing to innovation, such as R&D, referred to as *searching*, generally look for alternatives (in terms of products, processes, markets, etc.) close to the ones already well known to the organisation, as suggested by the idea of technological trajectories.

Nelson (1993) and his collaborators conducted a major empirical study and comparison of the national innovation systems of 15 countries. They concluded that "to a considerable extent, differences in innovation systems reflect differences in economic and political circumstances and priorities between countries." Again, these differences reflected the differences in the institutional set-ups between different countries, including systems of university research and training and industrial R&D, financial institutions, management skills, public infrastructure and national monetary, fiscal and trade policies.

The concept of 'National Innovation Systems' has proved useful, and was developed and applied by the Organisation for Economic Cooperation and Development (OECD) in a 7 year long study (1995 to 2002) of empirical, analytical and policy work covering 24 countries (OECD 1999; OECD 2002). The first obvious difference between countries is that they vary in their size and their level of development, which affects their innovation capacity. The second is that differences in the institutional set up mean that countries vary in the respective roles of the main actors in innovation processes (firms, public and private research organisations, and government and other public bodies), and in the forms, quality and intensity of their interactions.

Technological Innovation Systems

Recent work has applied similar ideas to technological innovation systems, defined as: "….networks of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, defusing, and utilising technology" (Carlsson & Stankiewicz 1991). The three main elements of technological innovation systems are identified in Jacobsson & Bergek (2004) as:

- *Actors (and their competencies)***,** including firms, users, suppliers, investors, and other organisations;
- *Networks*, defined as the channels for the transfer of tacit and explicit knowledge; and
- *Institutions*, being the entities that govern and dictate the environment within which all actors operate.

Based on a review of analyses of innovation systems, Jacobsson & Bergek (2004) identify five processes or 'functions' that characterise a successful technological innovation system:

- *Creation and diffusion of 'new' knowledge*;
- *Influencing the direction of the search process* among users and suppliers of technology, i.e. to influence the direction in which actors deploy their resources;

- *Supplying and mobilising resources*, including capital, competencies and other resources;
- *Creating positive external economies* through the exchange of information, knowledge and visions;
- *Facilitating the formation of markets*

The identification of these functions enables the analyst to trace the way through which, for example, a particular combination of actors or specific institutional set-up shapes the generation, diffusion and utilization of a new technology. It is then possible to identify a number of mechanisms that may induce or block the development of effective functions for particular technology systems. *Drivers or inducement mechanisms* may include: government policy (e.g. R&D funding, investment subsidies, tax incentives); ease of firm entry; and feedback from market formation. *Barriers or blocking mechanisms* may include: uncertainty; lack of political support; poor connectivity of networks; opposing behaviour of established firms: and disincentives created by other government policies.

Jacobsson & Bergek (2004) identify two broad phases in the evolution of a product or industry: (1) ‘formative period’ and (2) ‘market expansion’. These differ in terms of: character of technical change, patterns of firm entry/exit, and rate of market growth. In the formative period of technology development, there is usually a range of competing technology designs and many entrant firms, which are typically small. These firms face high uncertainties, in terms of technologies, markets, regulations. If there exists suitable niche markets, these can act as ‘incubation rooms’, where learning occurs, price/performance of the technology improves and new customer preferences can form. However, there are likely to be strong barriers to technological change, arising from the high uncertainties, the lock-in of existing technologies and institutions, weak networks amongst actors advocating change, and lack of a long-term vision of how the new technology could develop. Drivers for change come from feedbacks from formation of markets, through learning effects and price/performance improvements; entry of new firms contributing to creation of new knowledge and designs and supply of resources and skills; and government policy, through support for R&D, investment subsidies, demonstration programmes and regulatory changes. If the drivers for change are stronger than the barriers to change in the circumstances relating to a particular technology, then that technology can progress to the ‘market expansion’ phase. In this phase, a ‘dominant design’ for the technology emerges, and initial markets grow and coalesce to give rapid market growth, as the increasing returns or positive feedbacks to the adoption of the technology kick in.

The functions of innovation systems approach has much in common with the approach described in Section 2 which combines innovation systems ideas with an ‘innovation chain’ of the stages of technology development, whilst providing slightly different emphasis on some features.

Box 1.2: The German Wind Turbine Industry

Based on analysis of how these inducement and blocking mechanisms interacted in practice, Bergek & Jacobsson (2003) identify four factors that contributed to the relative success of the German wind turbine industry:

1. Creation of variety in an early phase, as large numbers of small wind generation firms entered the market;
2. Establishment of the social legitimacy of wind energy, through strong lobbying by wind firms and non-governmental organisations (NGOs);
3. The employment of advanced market creation policies in a later phase, particular the German 'feed-in' law which guaranteed a market price for renewable generation and required suppliers to connect wind farms to the electricity grid; and
4. The use of industrial policy to favour the domestic industry, again through the feed-in law.

1.5 Key themes from innovation systems theory

Three key themes may be identified as arising within the above innovation systems approaches. These are: (1) Systemic interactions between users, producers and technology developers; (2) Uncertainty and 'bounded rationality'; (3) The institutional set-up.

(1) Systemic interactions

Perhaps the most important insight that the new innovation literature provides is into the importance of a systems approach to understanding innovation. This leads beyond the old linear model of innovation, whereby an increase in R&D going in at one end will automatically lead straight to new products and services that emerge at the other end of the process. The systems approach also suggests that the rationale for government intervention to support innovation goes beyond a simple 'market failure' external benefits argument, whereby support should reflect the difference between the private rate of return to R&D and the social rate of return. Systems thinking does not diminish the role or importance of R&D in generating innovation; rather it provides a more complex picture of the drivers of the rate and direction of innovation, and of the barriers that can prevent successful innovation.

The picture of the innovation process and system which emerges from this approach is of a range of actors or players that interact through both market mechanisms and flows of knowledge and influence, within an institutional set up which creates incentives for different types or rates of innovation. This implies an additional role for policy related to improving the institutional set up and developing or exploiting opportunities for constructive interactions so as to provide better incentives to move in the desirable directions of innovation. This may be thought of as correcting for '*systems failures*' in the innovation system, such as failures in infrastructure provision, transition failures, lock-in failures, and institutional failures (OECD 2002).

As the OECD admits, the National Innovation Systems framework provides more of a new conceptual approach, rather than a 'quick fix' to innovation policy. Indeed, Edquist (2001) argues that, because of the evolutionary and institutional basis of the systems approach, it is not possible to compare the current state of systems to some theoretical optimal state. Hence, he argues that "there is no alternative to a pragmatic basis for innovation policy design", based on concrete empirical studies and comparative analysis between different innovation systems. Similarly, the general lessons from the OECD NIS study are about the need to refocus policy attention:

- From considering ‘optimum’ or ‘equilibrium’ solutions to examining real-world problems and the effectiveness of solutions, including systemic and government failures, as well as market failures.
- From ‘universal’ to ‘context-specific’ determinants of economic performance.
- From stocks to flow of knowledge as drivers of innovations.

(2) Uncertainty and ‘bounded rationality’

The second common theme relates to the role of uncertainty and ‘bounded rationality’. As emphasised within evolutionary approaches, ‘bounded rationality’ is the idea that firms or individuals are always limited in their ability to gather and process information relevant for their decision-making. As a result, rather than making the perfect, optimal choice from a given range of options, they ‘satisfice’ by choosing an available option that meets their preferred criteria. This marks a clear break with neo-classical economic models, which assume that actors are perfectly rational, so that, for example, firms always act to maximise their profits. Clearly, firms that ignore profit-making criteria will soon go out of business, but they may consider profits above a certain threshold constraint to be satisfactory.

Once firms are not assumed to have perfect knowledge, what they know and how they learn becomes central to understanding the innovation process. Much innovation consists of making new combinations of existing knowledge, as a result of the various forms of learning (as discussed in Section 1.3): *learning-by-doing, learning-by-using* and *learning-by-interacting*. Hence, to understand innovation it is important to try to appreciate how these learning processes work for different technologies and industries. The ability to learn, and hence to innovate, also depends on the existing knowledge and skills of the firm’s employees.

Finally, bounded rationality implies that firms’ expectations of the future are a crucial influence on their present decision-making. Innovation is necessarily characterised by uncertainty about future markets, future technology potential and future policy and regulatory environments. Hence, firms’ expectations of these factors will influence the directions of their innovative searches. As expectations are often implicitly or explicitly shared between different firms in the same industry, this helps to explain why the development of technologies tends to follow particular trajectories. A shared expectation can even come close to being a self-fulfilling prophecy (MacKenzie 1992). The most well-known example is ‘Moore’s law’, that the number of components on state-of-the-art microchips, and so the computing power, will double every 12-18 months. This widely known ‘law’, formulated by semiconductor pioneer Gordon Moore in 1964, has held remarkably well from the first transistor in 1959 to present day chips, and may well have guided the efforts of innovators in the semiconductor industry (Hiremane 2005).

(3) Institutional set-up

The third common theme is the influence of the institutional set-up or framework on the rate and direction of technological innovation. As noted, institutions provide the ‘rules of the game’, covering property rights, contractual relations and policy and regulatory frameworks. Institutional economics describes different levels of stability, ranging from market interactions that are continuously changing, through formal institutions with lifetimes of several years, to cultural values which only change over decades or centuries. The prevailing set of technologies and institutions forms a technological regime, which helps to guide innovation. Section 1.5 discussed the idea that a transition to a new technological regime occurs through the development and cumulation of niches, in which learning can occur, at least partly insulated from the demands of the current regime.

1.6 Summary

The systems view of innovation thus provides a richer picture of how technologies and new technological systems emerge. Key themes of the systems approach are (1) the systemic interactions between firms and other organisations, networks and institutions which together form a (technological) innovation system; (2) the importance of learning within the system and expectations of the future, as a consequence of uncertainty and limits to organisations' ability to acquire and process all the information relevant to decision making; (3) the influence of the institutional set-up of relations, routines and regulatory frameworks on the rate and direction of technological innovation. The next Section considers the application of the systems approach to innovation in low-carbon technologies.

2 Application of innovations systems theory to energy technology policy

The previous section described how a systems approach provides a richer picture of the process of technological innovation and associated institutional change.

This section begins to describe how these ideas can be applied to energy technology innovation policy for mitigating climate change. It argues that there are two complementary levels that need to be addressed.

- **Firstly, setting out a clear strategic framework to promote a transition to a low carbon economy, in order to overcome the current state of 'carbon lock-in'.**
- **Secondly, implementing specific measures to promote innovation and deployment of low carbon technologies.**

These measures should complement signals provided by a carbon price (a necessary but not sufficient aspect of policy) and measures to overcome non-market barriers.

2.1 Introduction

There is a need for a clear strategic framework to deal with the barriers created by the success of existing high carbon energy technologies in forming resilient, 'locked-in' systems for meeting consumers' energy demands. Section 2.1 explores how this state of 'carbon lock-in' helps to explain why incremental measures may not be enough to promote a transition to a low carbon system. Section 2.2 examines the need to create a long-term strategic framework to promote a transition, and briefly explores one approach now being applied to energy policy in the Netherlands. Clearly, a strategic framework to be applied in Australia would need to be appropriate to local conditions, but some lessons could be carried over from the Dutch transition approach. Section 2.3 describes the rationale for energy technology innovation policy, and outlines potential policy measures to promote innovation and deployment directly. Section 2.4 explores the key issues of balancing support for diversity and learning benefits. Section 2.5 addresses barriers to the adoption of low carbon technologies.

2.2 Understanding carbon lock-in

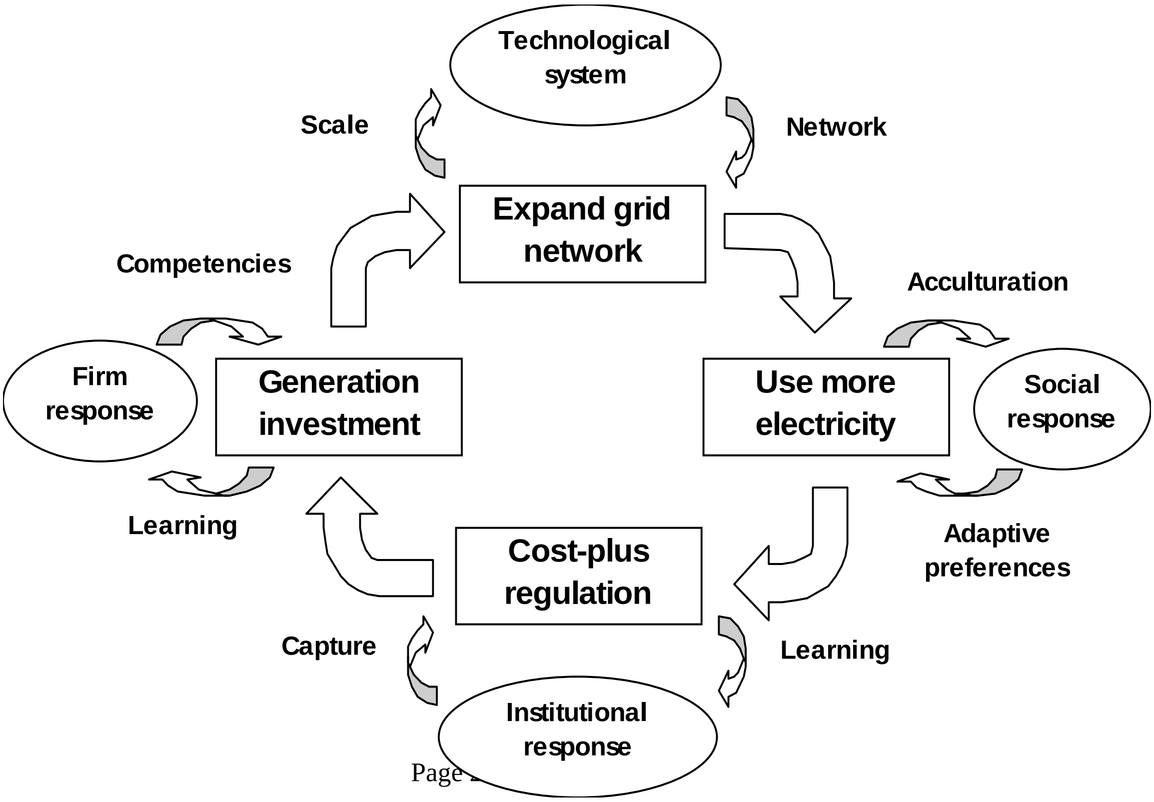
Gregory Unruh (2000; 2002) has spelt out the implications for energy systems of the 'path dependency' ideas discussed in Sections 1.2. Unruh argues that industrial economies are in a state of *carbon lock-in* to current carbon intensive, fossil fuel-based energy systems; this state creates persistent market and policy failures that inhibit the diffusion of carbon-saving technologies, even where they have environmental and economic advantages. He argues that this situation results from a process of technological and institutional *co-evolution*, driven by path-dependent increasing returns to scale. As Section 1.2 argued, there are four classes of increasing returns (positive feedback) to the adoption of technologies: *scale economies, learning* *effects, adaptive expectations* and *network economies*, and similar types of increasing returns apply to institutions (i.e. the relatively stable rules and conventions that govern economic behaviour), meaning that once in place, technologies and institutions acquire a momentum which makes them hard to re-direct.

Unruh (2000) introduces the notion of a *Techno-Institutional Complex*, to capture the idea that lock-in occurs through combined interactions among technological systems and governing institutions. A technological system is an inter-related set of components connected in a network that includes physical, social and informational elements. Unruh notes that automobile-based transport systems and large centralised electricity generating systems both have *'dominant designs'* (Utterbach 1994) based on fossil fuels, which define *technological trajectories* along which firms incrementally develop their know-how. Whilst pursuing the development trajectory improves the dominant design, it can also act to limit the knowledge-base and restrict investment choices of successful firms, which tend to follow the *core competencies* that form the basis of a company's competitive advantage (Christensen 1997).

The way in which large technological systems are financed can act to further exacerbate lock-in conditions. Investment capital, whether funded by companies' internal cash flow or retained earnings, or by risk-averse external financial institutions, tends to go to companies with collateral and a proven ability to service debt; these are likely to be the dominant design producers. Funding for potential radical or 'disruptive' innovations tends to come mainly from venture capital or government research programmes with much stricter lending conditions or higher costs (Christensen 1997).

The electricity generation Techno-Institutional Complex forms an example where institutional factors like the combination of the desire to satisfy increasing electricity demand and a regulatory framework based on reducing unit price, feed back into expansion of the technological system. Figure 2.1 illustrates this.

Fig. 2.1 The electricity generation techno-institutional complex (Unruh 2000)



In this stylised picture, government incentive or approval allows investment in new generating capacity, which expands the scale of the technological system. As the system expands, increasing returns mechanisms drive down costs and increase the reliability and accessibility of the system. The increased availability of cheap electricity stimulates a social response in the form of increased consumption, together with providing a stimulus for new applications and end-use technologies. The institutional regime, based on reducing unit price, creates an incentive for firms to invest in new generating capacity, rather than energy efficiency measures. This creates a positive feedback system in which technological and institutional factors reinforce each other to produce a rapidly expanding generating system and an incentive to consume more electricity.

In the absence of clear signals to the contrary, Pierson (2000) noted that organisations that have power or influence under the current institutional set-up will generally act, e.g. through lobbying, to ensure that any changes to the system do not reduce their power. However, a credible strategic framework that signals a clear future direction for a transition to a low carbon energy system, could help to persuade incumbent firms to become leaders to help achieve such a transition. For example, incumbent Spanish electricity firms have invested strongly in developing wind generation following a clear strategic commitment and deployment support from their government (Stenzel et al. 2007).

2.3 Overcoming carbon lock-in

This report argues that overcoming this state of carbon lock-in requires action at two complementary levels. Firstly, there is a need to set out a clear strategic framework to promote a transition to a low carbon economy. Secondly, specific measures need to be implemented to promote innovation and deployment of low carbon technologies (see Section 2.4). These measures should complement signals provided by a carbon price and measures to overcome non-market barriers (described in Section 2.5).

The importance of a clear, long-term strategic framework for promoting a transition to a low carbon economy has been recognised, at least in principle, by a number of European governments. However, what has so far been put in place has not yet played the key role of providing a clear framework within which the likely effectiveness and coherence of individual policy measures can be assessed.

In November 2007, the UK Government introduced a Climate Change Bill into Parliament with the aim of becoming law by spring or early summer 2008. The Bill aims to provide a clear, credible, long-term framework for the UK to achieve its goals of reducing carbon dioxide emissions, as shown in Box 2.1.

Box 2.1: The UK Climate Change Bill

Key provisions of the UK Climate Change Bill are:

- To put into statute the UK's targets to reduce carbon dioxide emissions through domestic and international action by at least 60 per cent by 2050 and 26-32 per cent by 2020, against a 1990 baseline.

- To review this target, based on a report from the new independent Committee on Climate Change on whether it should be even stronger still, and the implications of including other greenhouse gases and emissions from international aviation and shipping, in the target.
- To put in place five-year carbon budgets, which will set binding limits on carbon dioxide emissions. Three successive carbon budgets (representing 15 years) will always be in place, to provide a balance between predictability and flexibility.
- Emission reductions purchased overseas may be counted towards the UK's targets, consistent with the UK's international obligations. This ensures emission reductions can be achieved in the most cost effective way, recognising the potential for investing in low carbon technologies abroad as well as action within the UK to reduce the UK's overall carbon footprint.

The UK faces a huge challenge to put in place an effective and coherent mix of measures and incentives across systems for meeting public, industrial and domestic demands for energy, transport and heat services to ensure that these targets will be met. Three criticisms of the UK policies so far (Anderson 2006; Anderson 2007) are that:

1. It has been far too short-termist, and subject to frequent revisions, despite having laudable long-term targets; for example, the renewable energy target has only recently been extended to 2020, while for transport generally weak incentives are due to be phased out by 2012 (though they too will probably revised in due course).
2. With the recent exception of wind energy for electricity generation, the incentives have been too weak to promote innovation and deployment of new technologies.
3. There has been an excessive focus on particular technologies and sectors—transport is a conspicuous near-omission, while carbon capture and storage has received only belated attention.

The extent to which the Climate Change Bill will provide a clear framework for overcoming these shortcomings remains to be seen.

A different approach is being pursued in the Netherlands. Following its proposal in the 4th Netherlands Environmental Policy Plan (NEPP), published in 2000, the Dutch Government has adopted a 'Transition Approach' to promote a long-term transition in energy systems (Kemp & Rotmans 2005; Netherlands Ministry of Economic Affairs 2006). Key characteristics are its long-term orientation, its systems approach, the collaboration between government and stakeholders, and specific actions in the short term. For each priority area chosen, visions for the future and medium-term (20 year) strategic goals are developed (where do we want to go?), 'transition paths' are formulated (how are we going to get there?) and 'transition experiments' proposed (how are we going to travel the paths?). This is based on a 'learning-by-doing' approach - undertake experiments; design learning goals into experiments; feed back lessons into subsequent measures. This framework has been applied to exploring transitions to decarbonised energy systems in the UK by Shackley and Green (2007).

The Netherlands Ministry of Economic Affairs (2006) argues that this requires a new form of concerted action between market and government ('policy renewal'), based on:

- *Relationships built on mutual trust*: Stakeholders want to be able to rely on a policy line not being changed unexpectedly once adopted, through commitment to the direction taken, the approach and the main roads formulated. The government places trust in market players by offering them 'experimentation space'.
- *Partnership*: Government, market and society are seen as partners in the process of setting policy aims, creating opportunities and undertaking transition experiments, e.g. through ministries setting up 'one stop shops' for advice and problem solving.
- *Brokerage*: The government facilitates the building of networks and coalitions between actors in transition paths.
- *Leadership*: Stakeholders require the government to declare itself clearly in favour of a long-term agenda of sustainability and innovation that is set for a long time, and to tailor current policy to it.

This clearly reflects a tradition of a more consensual Dutch process between policy-makers and industry than in some other countries. However, it provides an interesting model from which to pull out key concepts, i.e. a range of public and private actors coming together to agree a long-term vision for future energy systems, putting in place a strategic framework for achieving it and continuing to work together in an open and constructive manner involving mutual learning. Such an approach would help to create positive expectations and a stable framework that would encourage investment for the long-term.

A key element within the Dutch transitions approach is the identification and promotion of *niches*, i.e. situations or locations in which technological alternatives may have a particular strength, in comparison to mainstream markets. Because niches are in some way insulated from 'normal' market selection in the regime, they act as 'incubation rooms' for radical novelties (Geels 2002; Kemp 2000; Schot 1998). Niches provide locations for learning processes to occur, i.e. learning-by-doing, learning-by-using and learning-by-interacting. They also provide space to build up the social networks that support innovations, e.g. supply chains, user-producer relationships. The idea of promoting shifts to more sustainable regimes through the deliberative creation and support of niches, so-called *'strategic niche management'*, was put forward by Kemp and colleagues (Kemp et al. 1998).

2.4 Low carbon innovation policies

Rationale for innovation policy

In order to achieve the innovation and deployment of a range of low carbon technologies to meet long-term emissions reduction targets, specific measures to promote low carbon innovation will be needed. The next section explores particular policy measures and lessons to be learned. This section sets out the rationale for government interventions to promote low carbon innovation, which is increasingly being accepted by economists and others.

The orthodox economic rationale for interventions to promote low carbon innovation focuses separately on the two market failures associated with the environment and innovation. The harmful externality associated with unpriced carbon emissions is addressed by measures to ‘internalise this externality’. This can be attempted through the use of ‘market-based’ or ‘economic’ instruments, such as carbon taxes or tradable permit schemes, such as the European Union’s Emissions Trading Scheme, or through regulation or voluntary agreements. The market-based approach provides a ‘market pull’ by creating an economic value to mitigating carbon emissions and an incentive to continue to search for less costly ways of doing so.

The externality associated with innovation relates to the fact that since new knowledge is often easy to copy, innovators cannot always appropriate the full benefits of their investment in knowledge creation, and so private firms may lack the incentives necessary to undertake socially efficient levels of innovative activity. In economic terms, there are some unpriced external benefits from innovative activity such that the social returns to innovation exceed the private returns (Arrow 1962a). Thus some innovative activity has the characteristics of a *public good*, in that it is non-rival and non-excludable. Innovation is generally *non-rival*, in that once created, its use by one agent does not reduce the amount/quality available for use by others, and hence, it is not desirable to ration access to it. It is *non-excludable*, since once supplied, it is hard to deny access to other users. This means that it will be undersupplied by the market because it cannot exclude non-paying *free riders*. In other words, the benefits of innovation spill over to others from the firm undertaking the innovative activity, i.e. there are positive externalities. These features provide a rationale for public support for innovation, particularly at the early stages of R&D and demonstration when new products or services are far from market and risks to innovators are high.

Environmental economists have increasingly recognised, however, that these two market failures may strongly interact (Jaffe et al. 2005). Consequently, there is a danger that if they are considered completely separately, potential for both positive and negative interactions between policies may be missed. Hence, policy measures should seek to promote environmentally-beneficial innovation, as a complement to measures to put a price on carbon emissions. This has at least three benefits. *First*, it is an attempt to recognise the positive externalities of innovation discussed above, which are overlooked by economic analysis of pollution abatement focusing only on direct economic incentives. *Second*, in the presence of appreciable uncertainties and risks, it recognises the importance of having a diverse portfolio of options, including options which have large potential but which are currently higher cost and so may easily be excluded in a deterministic analysis. *Third*, the practical argument is that it has proved possible, in all OECD countries, to win political and public acceptance of direct support for innovation and addressing market ‘barriers’ to the uptake of new low carbon technologies and energy efficiency.

The innovation systems approach suggests a rationale for innovation policy based on the identification of ‘systems failures’, to be discussed in Section 3.2. However, the language of ‘systems failures’ has not yet been widely adopted. Current policy approaches thus generally follow a pragmatic approach to promoting environmentally-beneficial innovation based on the above three benefits.

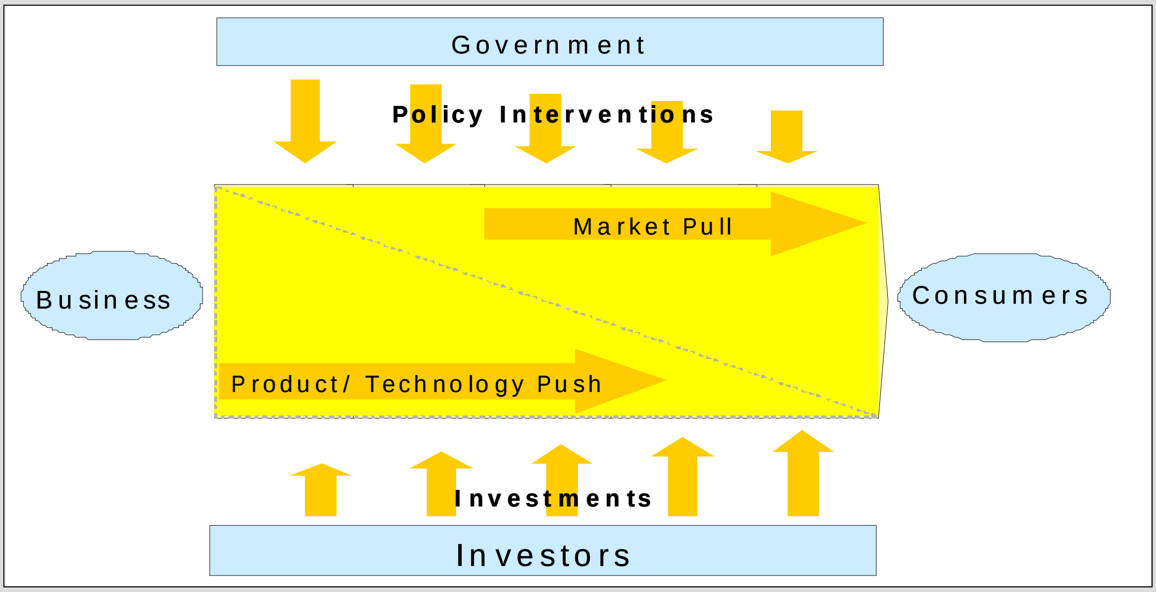
The innovation chain

A key insight from innovation systems theory is that different drivers and barriers are at work at different stages in the development and commercialisation of a technology.

So, it is helpful to be more explicit about these stages of development, in order to inform the types of policy measure that may be appropriate at different stages.

The ideas in Section 1 present a more complex picture of the innovation process than is represented by a simple linear progression from R&D to commercialisation to diffusion. As well as emphasising the roles of different actors, the importance of feedbacks, both positive and negative, between different parts of the system is stressed. Nevertheless, the systems approach still recognises the existence of stages of technology development within the innovation process. The innovation chain, shown in Figure 2.2, provides a representation that includes the various actors and institutions and gives an overview of how they interact with the different stages of the innovation process.

Fig. 2.2. Stages of technology development: The ‘innovation chain’ (Foxon 2003)

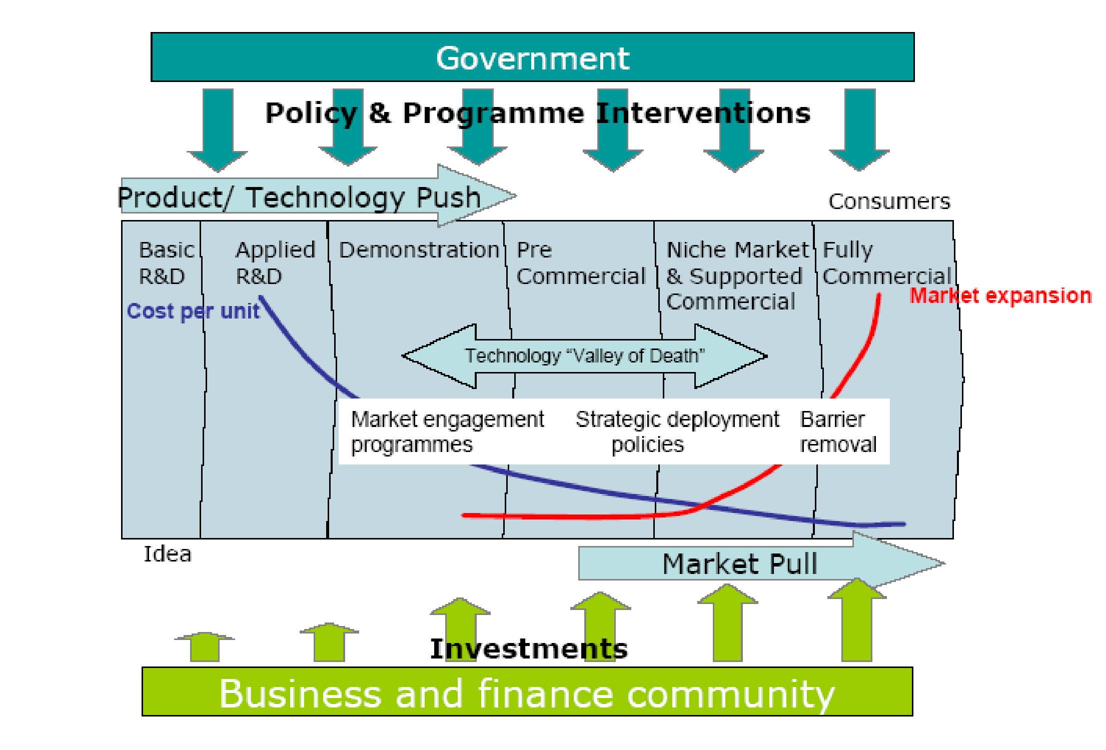


- The innovation process involves the development and deployment of new technologies, products and services by business in order to meet the needs of consumers. To achieve this, funding is required from a variety of investors, such as insurance companies, banks, private equity houses and angel investors.
- In the early stages of the market, take-up is largely driven by the product/technology push. As consumer awareness builds, the rate of deployment is accelerated as consumer demand grows.
- Government can make various policy interventions at various stages of the innovation chain to overcome barriers to the development of various technologies, products and services.

Progress of a technology along the innovation chain relies on interactions between the actors, networks and institutions within the relevant technological innovation system. The linear model of innovation starts from the basic drivers of basic drivers of ‘technology push’, from the development of new ideas, and ‘market pull’, from the demand for market solutions. The innovation systems approach recognises that these drivers play important roles, but argues that they do not encompass all the systemic interactions.

It is frequently observed that new technologies face a ‘valley of death’ in progressing through the intermediate stages of the innovation chain, due to multiple risks and uncertainties (Grubb 2004; Murphy & Edwards 2003); see Figure 2.3. Hence, a mix of policies is needed to promote successful innovation, which goes beyond just support for R&D and pricing carbon emissions. Governments throughout the OCED have begun to recognise this by providing incentives to support demonstration and the commercialisation of new technologies directly, for example through feed-in tariffs (much of Europe), marketable permits or 'obligations' to use the technologies (the UK), portfolio standards (the US) and procurement policies (most countries).

Figure 2.3. Interventions along the innovation chain (Grubb 2004)



Mix of policy measures

As described in Chapter 16 of the Stern Review (Stern 2007), in the light of this complexity, three broad types of measure will be needed within the overall climate policy mix:

1. Carbon Pricing, through taxes, tradable permit schemes, carbon contracts and/or implicitly through regulation.
2. Direct support for innovation in the form of:
    - Tax or other incentives for private R&D combined with finance for public R&D in public research institutions and universities;
    - Tax incentives and/or grant finance for demonstration projects;
    - Public procurement of innovative technologies—such as solar roofs and micro-generators for public buildings, fuel cells for the defence and aerospace industries and for demonstrator buses, and so forth;
    - Regulatory incentives and standards for low carbon technologies (low carbon vehicles for example, and efficiency standards in buildings and for a large number of appliances);
    - Price support mechanisms, again for innovative technologies in their early phases of development—examples include feed-in tariffs in several EU

countries, the Renewables Obligation in the UK[2] (also the former Non Fossil Fuel Obligation programme[3]) and more recently the Renewable Transport Fuel Obligation (RTFO);[4]

- Tax credits for investment in or the use of innovative technologies.

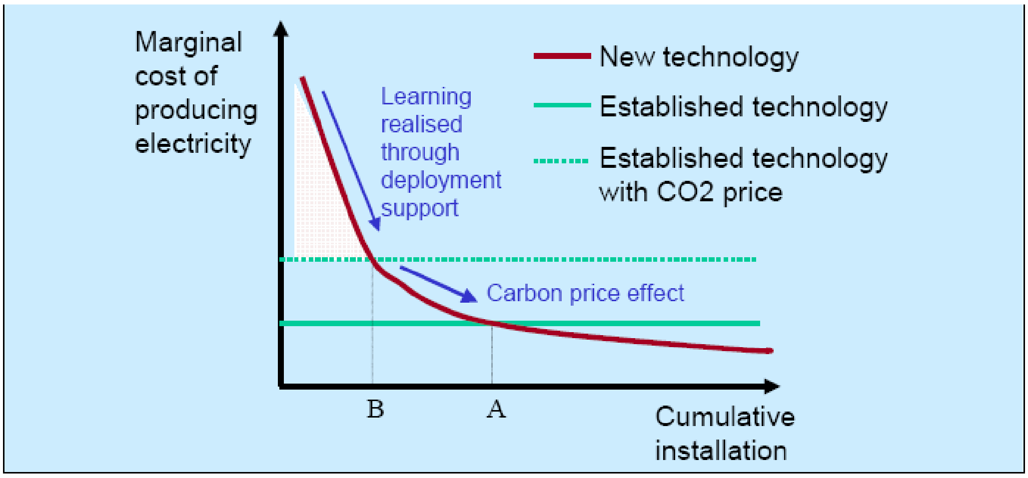
3. Addressing 'barriers' to adoption—shortcomings in the patent system, labelling on the performance and efficiency of appliances, congestion pricing to reduce the social costs of congestion, and various other.

Our review of innovation theory supports the Stern Review's conclusion that carbon pricing alone will not be sufficient to reduce emissions on the scale and at the pace required to mitigate human-induced climate change. This is because of:

- The risks associated with investment in low carbon technologies arising from the problem of the credibility and durability of future carbon prices which depend on the continuation and extension of current government policies and international agreements.
- The uncertainties and risks of the rates both of climate change and of development and deployment of new technologies.
- And, as indicated, the positive externalities of innovation.

As the Stern Review suggests, carbon pricing and direct innovation support play complementary roles in bringing technologies along the innovation chain. Carbon pricing will (it is to be hoped) assume a more important role in future; it is especially well-suited, as the Stern Review showed, as an incentive for the adoption of the mature low carbon options, with direct support for innovation assuming greater responsibility in the earlier phases of a technology's development. Figure 2.4, taken from the Stern Review summarises the argument very well:

Figure 2.4. Interaction between carbon pricing and deployment support (Stern 2007)



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[2] http://www.dti.gov.uk/energy/sources/renewables/policy/renewables-obligation/page15630.html

[3] The NFFO and the Scottish Renewables Obligation (SRO), imposed by the Electricity Act 1989, were the Government's main renewable energy policy instrument before the RO in 2002.

[4] http://www.dft.gov.uk/pgr/roads/environment/rtfo/.

To go beyond this general argument, it is necessary to undertake detailed analyses of particular technological innovation systems to assess the particular mix of policy measures that would be appropriate. (Section 3 sets out a theoretical framework for undertaking such analyses.) Table 2.1 illustrates that several important measures to promote innovation are inherently technologically prescriptive[5]. If climate policies require investment to be directed towards particular technologies or technology types then investment conditions matter to policy.

Table 2.1: Policy instruments, high level objective and technological specificity (Gross et al. 2007)

Option/intervention	**High level objective (Stern 2007)**			**Technology specific?**
	Price carbon	Overcome non market barrier	Promote innovation/new technologies[6]	
Cap and Trade	Yes	No	~	No
Carbon tax	Yes	No	~	No
RPS schemes (e.g. the RO)	No	No	Yes	Yes *
Fixed price revenue support (e.g. Feed in Tariff)	No	No	Yes	Yes
Capital subsidies	No	No	Yes	Yes
Grants for RD&D	No	No	Yes	Yes
Direct regulation (electricity supply)	No	No	?	?
Regulation (electrical appliances)	No	Yes	?	?
Labelling (electrical appliances)	No	Yes	?	?

Yes = positive impact: No = zero or very limited impact: ~ Limited/secondary effect:

? Possible depending on policy design

* Degree of specificity depends upon design – for example the RO is technology neutral but within category of technology/resource (renewables), and could be more specific if banded by technology.

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[5] There is some debate in Britain over the advisability of government ‘picking winners’. British policy orthodoxy is that governments should avoid any attempt to determine which technologies are best suited to solving any given policy problem (see (Watson 2006)). The UKERC report contends that innovation policies are inherently technologically specific and the notion that governments must not, or indeed do not already, ‘pick winners’ is unhelpful and misleading.

[6] Innovation is indirectly induced by most policies, including carbon pricing and regulations – however some policies are intended to *promote innovation directly* and these are the object of this column.

2.5 Balancing support for diversity and learning benefits

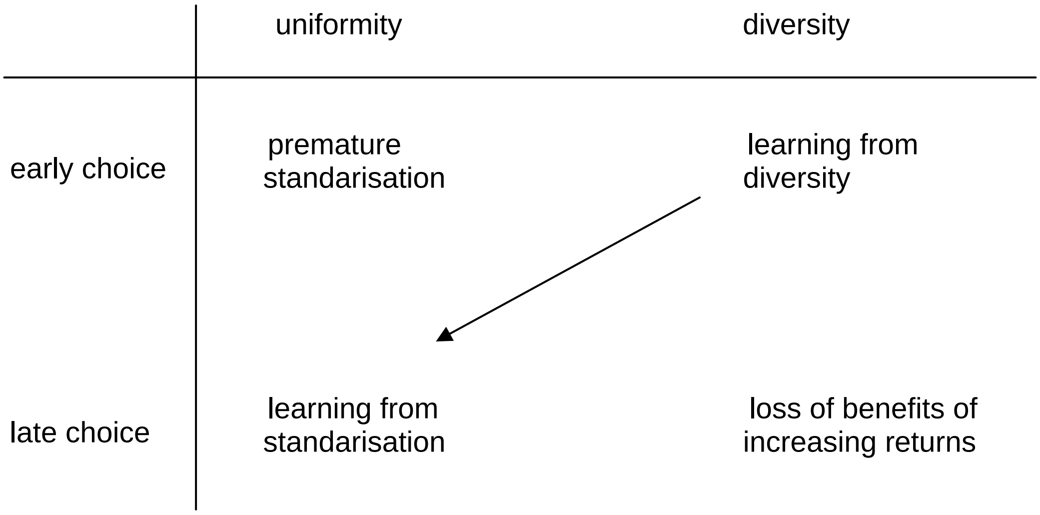
The key aim of innovation support mechanisms is to ensure that new technological alternatives benefit from increasing returns, giving rise to positive feedbacks as they are adopted (Marechal 2007). The first two classes – '*scale economies*' and '*learning effects*' are well documented and give rise to empirically observed 'learning curves'(see Box 1.2) Learning curves show that the unit costs of a new technology typically fall with increasing penetration of the technology into the market. These falls are measured by the 'learning rate', i.e. the reduction of unit costs of a technology with a doubling of cumulative installation. For technologies in the early stages of development, learning rates of 10 to 20% are typically observed (McDonald & Schrattenholzer 2001; Junginger et al 2005).

As will be discussed in Section 4, however, investment in low carbon technologies depends on assessments of the risks and uncertainties associated with future revenue streams, as well as future costs.

The importance of deployment support is also highlighted by the other two types of increasing returns to adoption: '*adaptive expectations*', which refers to a reduced level of uncertainty as both users and producers become more confident about the technology's general quality and reliability; and '*network externalities*', which refer to the benefits that a user derives from a technology when the number of other users increases, as with telephone systems. Support for technology deployment enables other potential users and producers to gain confidence in the future performance of the technology, as well as the direct learning benefits to those involved. It also helps to enable the development of a shared base of information and skills which would then be available to future developers.

The role of path dependency and sensitivity to historical conditions highlights that the challenge for policy makers goes beyond a simple dichotomy between technology-neutral market support and 'picking winners'. There may be a trade off between the potential for increasing returns to reduce costs and ease the transition to low carbon, and the risk of 'regret' as a result of lock in to an undesirable outcome. Foray (1997) has characterised the problem in terms of a four box matrix, with axes going from technological uniformity to diversity and from early choice to delayed choice, as in Figure 2.6 below. This shows the central dilemma very well – early lock-in may result in the 'wrong' option being selected (top left), whilst keeping options open indefinitely means the potential advantages of increasing returns cannot be fully realised (bottom right). Foray suggests that the optimal policy is to transit from the top right to bottom left box, but even then notes that there is some potential for regret due to lock-in based on choices made under previous conditions.

Figure 2.6. Balancing opportunities for learning and standardisation (adapted from (Foray 1997)



	uniformity	diversity
early choice	premature standarisation	learning from diversity
late choice	learning from standarisation	loss of benefits of increasing returns

Though there is no simple solution to this dilemma, the role played by niches in transitions to new technological systems, as shown in the previous section, suggests a way forward for policy makers. Niches represent ‘protected spaces’ in which learning can occur for new technologies, to some extent isolated from the pressure of competing with existing technologies in mainstream markets.

Some market niches arise naturally, for example photovoltaics may represent a competitive source of power for remote, off-grid applications. In many cases, however, niches may need to be actively developed by policy interventions. Measures to create a guaranteed price or share of the market for renewable generation or carbon capture and storage technologies could serve to create such a niche. They should be complemented by measures to overcome the institutional and non-market barriers to the deployment of the new technology.

2.6 Demand-side barriers to the adoption of low carbon technologies

Innovation policy has traditionally focussed on supply-side issues related to the initial development of new technologies. However, innovation systems theory argues that feedbacks from users on the demand-side are an important aspect of innovation processes as a whole. Hence, it is important to consider factors relating to the adoption of low carbon technologies alongside those relating to their initial development and, in particular, barriers that prevent their adoption.

As the Stern Review argued, the third policy strand, alongside carbon pricing and innovation support, is to address micro-level barriers to the adoption of low carbon technologies. Many of these barriers are familiar from cases of more energy efficient technologies and practices, where it is widely agreed that cost-effective opportunities are often not taken up. These barriers relate to information and decision-making at the firm- and consumer-level:

The problem of split incentives. The problem occurs whenever different actors would experience the costs and benefits of an investment in different ways. This is often known as the *tenant-landlord* problem, after the well-known case in which the landlord has no incentive to pay the costs of installing energy efficient technologies or insulation as the benefits of lower energy bills would accrue only to the tenant. Research by the Association for the Conservation of Energy (ACE) in the UK has shown that this is also a significant barrier to the take-up of energy efficiency measures in the commercial service sector (Scrase 2001).

Adverse selection. This arises where *asymmetric information* between the seller and the purchaser results in good products being driven out of the market by poorer products. Because, for example, developers do not factor running costs into the prices of buildings, more energy efficient buildings with higher up-front but lower running costs are often undercut by developers selling less efficient buildings.

Access to capital. The lack of access to capital is a barrier, for example to managers subject to direct capital constraints. Within commercial companies, capital is often rationed or less available for small investments. Organisations will impose much higher rates of return on small investments partly to offset transaction costs. This can be compounded by the *principal-agent* problem, in which the *principal* (say the manager in a firm) who has to make investment decisions has less information about the merits of the proposed projects than the *agent* (say the energy manager) who proposes the projects.

Transaction costs. The costs of finding information, negotiating agreements and contracts and organising purchasing agreements are all examples of transaction costs that are usually excluded from calculations of cost-effectiveness but can nevertheless be a significant impediment, the lowering of which could encourage further adoption.

In an analysis of barriers to energy efficiency in public and private organisations, Sorrell (2000) found that the major barriers to the take-up of energy efficiency measures were a lack of motivation coupled with competing demands on the times of decision-makers. These arose from constraints on staff time (the hidden costs of staff overheads) and a generally low priority given to energy costs within the companies' budgeting procedures. Similar barriers are likely to apply to the adoption of low carbon technologies more generally, as in many firms there is a general lack of awareness of, and accounting for, carbon emissions. As firms tend to demonstrate 'bounded rationality', they are not able or willing to gather or process all information potentially relevant to their decision-making. This means that they generally only search for incremental improvements to existing 'routines', which would satisfy existing evaluation criteria, and so neglect carbon accounting. In turn, this helps to reinforce the wider technological trajectory which the majority of firms within an industry are following. This is an area in which policy action to influence evaluation criteria could be significant.

2.7 Summary

This Section has analysed the challenge for low carbon innovation policy created by the lock-in of existing technologies and supporting institutions. This leads to the conclusion that innovation policy needs to go beyond just providing support for R&D

and market-pull through putting a price on carbon, and that there is a range of types of innovation policy measures available. It has also argued that these need to be considered within a long-term strategic framework to ensure coherence and effectiveness of the policy mix. To reach more specific policy conclusions, it is necessary to analyse in more detail particular technological innovation systems. Whilst it was beyond the scope of this report to undertake such analyses, a potential theoretical framework for this is set out in the next Section. Some specific areas for further research in the Australian context are set out in Section 5.

3 Theoretical framework for identifying barriers, failures and gaps within the innovation system

This section sets out a theoretical framework for identifying barriers, failures and gaps within energy technology innovation systems. This builds on the authors' previous work analysing UK renewables innovation systems, which used a framework adapted from OECD energy innovation systems studies.

This approach identifies 'systems failures' relating to the extent that current policy mixes for promoting innovation within systems serve to meet high-level policy objectives.

Generic innovation policy implications are then drawn out, including *creating, keeping open and closing off options*; *policy coherence, continuity and expectations*; and *prospective solutions to address 'systems failures'*.

3.1 Introduction

This section addresses the need for a theoretical framework for assessing energy innovation systems, in order to identify innovation barriers, failures and gaps. It builds on previous work on the case for support for environmental innovation (Anderson et al. 2001; Gross & Foxon 2003), and work done on UK innovation systems for renewable energy technologies for the UK Department of Trade and Industry (Anderson et al. 2003; Foxon et al. 2003; Foxon et al. 2005a). In that work, the authors applied the concept of 'systems failures' as a rationale for policy interventions. This concept comes directly out of innovation systems theory but, as noted in Section 2, the particular terminology has not yet been widely adopted.

3.2 Framework for analysis

It is now possible to begin to develop an analytical framework for assessing energy innovation systems, in order to identify innovation barriers, market failures and gaps. An appropriate analytical framework depends on both the questions to be addressed and the context of study. Box 3.1 describes a potential analytical framework for analysing low carbon technology innovation systems. This is based on the process undertaken in the authors' studies of UK renewables innovation systems for the UK Department of Trade and Industry' Renewables Innovation Review in 2003, which, in turn, was based on an adaptation of an approach used in an OECD comparative study of energy technology innovation systems in different countries[7]. This process could be adapted to the particular circumstance of Australian energy innovation systems.

The framework is summarised in Box 3.1.

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[7] See 'Sectoral Case Studies in Innovation: Energy' on the OECD website at http://www.oecd.org/document/25/0,3343,en_2649_201185_15708889_1_1_1_1,00.html

Box 3.1: Analysis of UK Renewables Innovation Systems for DTI Review

The analysis of UK renewables innovation systems for the DTI Renewables Innovation Review comprises the following five process stages:

Step 1. Develop generic model for analysing technology innovation systems

A generic model for analysing innovation systems for new energy technology sectors should involve three core components:

- Identification and characterisation of the key actors for each sector.
- Description and 'mapping' of the systemic interactions between these actors, and how these give rise to innovation.
- Comparison between the different sectors, and identification of common conclusions and key differences.

Step 2. Characterise new energy sectors

The mapping and analysis of each energy sector should lead to the identification of some key actors, and provide an initial description of technological alternatives. A more complete characterisation of the innovation system for each sector could then be pursued, with additional knowledge gained through interviews or workshops with key stakeholders.

Characterisation of each sector should consist of:

- First identifying the actors involved (academic researchers, technology developers, knowledge networks, project developers, technology end-users, research funders, financial investors, government departments and regulators);
- Identification of drivers of innovation, and the consequent flows of influence between the actors relating to their roles and activities;
- Exploring the ways in which knowledge is created, diffused and exploited by the different actors, arising from actors' different motivations within the innovation process;
- Creating an innovation map for each technology sector, in order to synthesise and summarise the main systemic interactions between the actors. Three main flows between the actors are represented on the map – influence, knowledge and funding.

Step 3. Conduct interviews

A generic set of questions for interviewees could be prepared, covering key areas of interest, for example, drivers for innovation; knowledge creation, diffusion and exploitation; public/private partnerships (PPPs); intellectual property rights (IPR); international dimension; and other systemic influences on innovation.

Step 4. Synthesis of outputs

The information gathered on each of the sectors is then brought together to answer the specific study questions. The initial maps of actors and flows are modified by inclusion of the results of the interview process. This should result in a detailed map for each sector, together with an analysis of the specific framework conditions. Specific 'systems failures' associated with particular technology sectors could then be identified.

Step 5. Analyse policy implications

The implications for the mix of policy measures needed to overcome the systems failures identified should then be analysed, and conclusions for policy makers drawn.

3.3 Identifying ‘systems failures’

The innovation systems perspective argues that the basic drivers of ‘technology push’, from the development of new ideas, and ‘market pull’, from the demand for market solutions, need to be considered in the light of systemic interactions between actors, who act in the face of uncertainty and bounded rationality, within particular institutional contexts. Thus, actors do not experience individual environmental or innovation market failures, but face their interaction in a systemic context.

Edquist (2001), Smith (1992; 2000) and Metcalfe (2003) have argued that the current concept of ‘market failure’, understood as a comparison between conditions in the real world and those of an ideal or optimal market system, is no longer appropriate. Instead, the concept of ‘systems failure’ is proposed as a rationale for policy interventions (Edquist 2001; Smith 2000). This advocates undertaking concrete empirical and comparative analyses, using innovation systems concepts, to identify systems failures that can be rectified. In this approach, two conditions are identified that must be fulfilled for public intervention to be justified in a market economy (Edquist 2001):

1. A *problem* must exist, i.e. a situation in which market mechanisms and firms fail to achieve objectives that have been socially-defined, through a public policy process.
2. The state and its agencies must also have the *ability* to solve or mitigate the problem (i.e. the issue of potential government and bureaucratic failure must be addressed).

In many cases, this concept of systems failure leads to similar or identical policy prescriptions to the concept of market failure, e.g. the use of market-based instruments to internalise negative environmental externalities. The crucial difference, however, is that it does not presume that public policy interventions can re-create ideal market solutions, which are assumed to have maximal economic efficiency. The systems failure approach is designed to help policy-makers identify cases where changes to rule-systems could lead to more effective achievement of social objectives without excessive costs or unnecessary bureaucracy. This approach is particularly relevant to the analysis of dynamic socio-economic systems, such as those involving radical innovation, where it is difficult or impossible to identify equilibria where optimal market solutions would pertain. In such cases, systems failures may be identified through empirical analyses of the effectiveness of current systems and comparative analyses of the effectiveness of systems operating under different legal and institutional rules.

3.4 Systems failures identified for UK renewables innovation systems

This approach combines ideas from innovation systems thinking with the innovation chain picture, shown in Figures 2.2 and 2.3. The authors' previous analysis (Anderson et al 2003; Foxon et al 2003; Foxon et al 2005a) argued that UK innovation systems appear to being failing at the intermediate stages in the innovation chain – developing and commercialising technologies that are emerging from R&D. This led to the insights described below.

System failure points

Technologies make progress along the innovation chain as a result of flows of funding, knowledge and influence between actors in the innovation system. On occasion, these systems can fail, and innovative products can get 'stuck'. At present, for some options, system failures or gaps appear to exist at two points:

1. *Moving from demonstration to pre-commercialisation*:

There are obstacles to companies seeking to move from the first one or two demonstration projects to more substantial (though still small scale) levels of deployment. The incentives offered by generic measures, such as the Renewables Obligation, cannot attract investment into technologies that are in their early stages of development, and so are high risk, high cost and confined to small niches. Potential remedies could involve support for niche markets, involvement of larger players and removal of R&D support for technologies not successfully progressing.

2. *Moving from pre-commercialisation to supported commercialisation*

Several types of risk are hindering the large-scale deployment of pre-commercial technologies (such as offshore wind and biomass). Policies address these in part, but the rewards may be not yet strong enough to overcome the risks. Hence, risk/reward ratios for project developers and investors need to be improved.

Expectations and knowledge about future markets are vital at all stages

Innovations in early stage technologies are predicated upon the expectation that there will be a supported market. Having unambiguous long term support, and a shared vision for the future, for each area of new and renewable energy, would have a self-reinforcing effect upon actors in the innovation systems for early stage technologies.

The continuity of the regulatory framework is important

The need for a long term framework and the longevity of the entire range of policies and regulations is important.

Technologies failing at the demonstration stage provide learning opportunities

Learning from unsuccessful technologies should be used as a stimulus for further technology development.

3.5 Generic innovation policy implications

Building on the basic argument for support for innovation and deployment given in Section 2, this type of analysis of innovation systems can help to identify an appropriate mix of policies in a particular national and institutional context. Here, we highlight the findings from our analysis of UK innovation systems that are likely to be generic to low carbon innovation systems.

Creating, keeping open and closing off options

The application of thinking about financial and investment 'options' to technological diversity suggests that there is a value associated with creating and keeping open 'options' which may be exercised in the future:

- To create an 'option' for meeting long term targets, new technologies need to move beyond R&D into the pre-commercial or supported commercial stage.
- The cost of keeping early stage options open needs to be investigated, but should not be prohibitively high, as total volumes are still relatively small. Potential benefits could be very large, in terms of both emissions reductions and national industrial benefits. Therefore, there is a strong case for policy support to keep early stage options open.

Policy coherence, continuity and expectations

There are benefits to a more strategic approach to policy development, which would aim to improve policy coherence, ensure continuity of policies over a longer time frame, and improve expectations of stability for technology developers and investors. Applying ideas from the Dutch transition approach described in Section 2.2, such a shared strategic vision for the transition to much higher levels of deployment of renewable energy technologies would:

- Agree strategic goals for the medium term.
- Set out transition paths or 'route maps' for how these might be achieved.
- Agree support for the initial steps or 'learning experiments' along these paths.

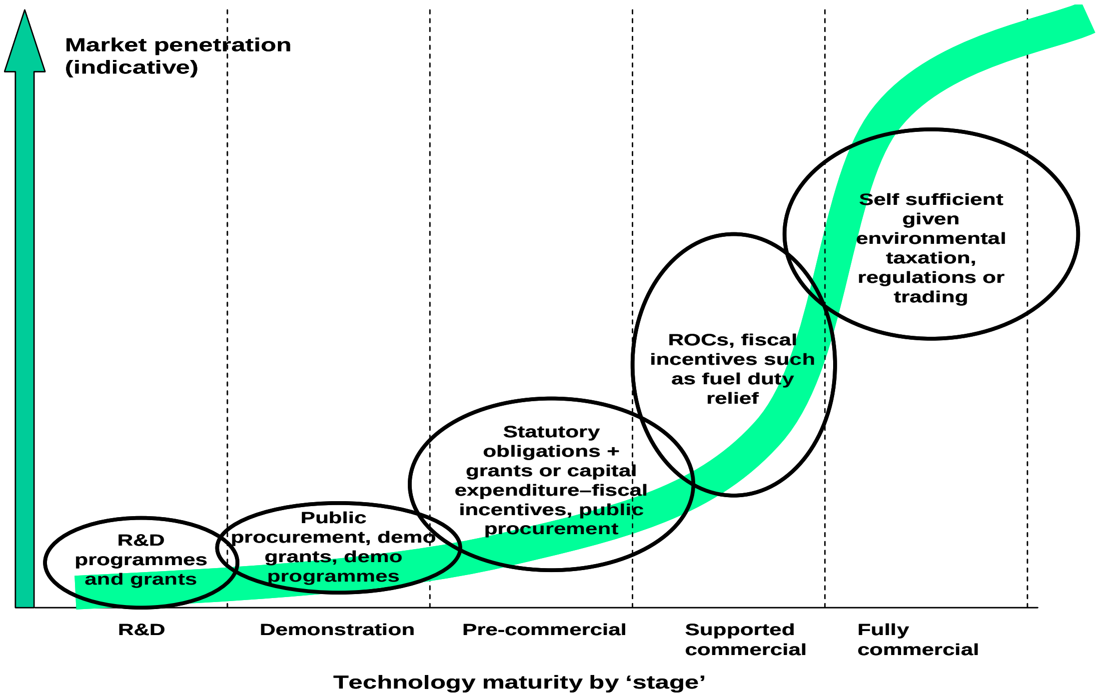
The benefits of such an approach would be to:

- Build on existing policy steps by placing these within a more strategic framework.
- Provide positive expectations of future policies and markets.

Within the strategic approach, key priorities should be to ensure:

- *Perseverance with policy frameworks* – policy measures to support innovation should be stable over the long-term and be insulated from short term political changes. Research suggests that policy uncertainty and reversals in the early phases of a technology's development can 'sink' an innovation no matter what its long term promise might be.
- *Regulatory consistency* – measures should add to the functioning of innovation support as a strategic whole, by augmenting and not disrupting existing measures.
- *Continuity of policy measures* – measures should 'join up' across the stages of the innovation chain, so that a successfully performing technology can progress smoothly towards commercialisation, with a clear strategy in place for withdrawing support at that stage. An outline of potential policy measures at each stage in shown in Figure 3.1.

Figure 3.1. Illustrative policy instruments at different stages of the innovation chain



Prospective solutions to address 'systems failures'

Specific 'system failures' that hinder the progress of renewables along the innovation chain are should be addressed. Addressing these requires new measures and new funds, but new money is not sufficient alone, implementation should take account of the strategic framework, and improve flows of influence and knowledge within the innovation system.

New measures are needed to address the systems failure or 'valley of death' associated with moving from the demonstration to the pre-commercial stage. Existing measures do not provide opportunities for small scale pre-commercial trials, so a new framework that creates a small niche market for technologies at this stage is needed. Different support mechanisms are available for achieving this:

- Premium prices, through either an early stage tranche within a portfolio standard, or a form of price support, such as a differentiated 'feed-in' tariff for technology options at different stages of development.
- A dedicated capital grants programme.

These mechanisms would aim to create a small niche market to allow early stage technologies move into pre-commercial trials.

Linked policies should also address the move from pre- to supported-commercial development. These should address the risk/reward ratio for project developers and investors at this stage, either by support that mitigates some risk, as in the capital grants programme above, or increases the potential rewards.

It is also important that 'exit strategies' are developed for withdrawing support from technologies which are successful in the supported commercialisation stage.

This mix of policies builds on the recommendations of the report by the International Energy Agency on ‘Creating markets for energy technologies’ (IEA 2003a), Box 3.2.

Box 3.2. Recommendations of IEA report on ‘Creating Markets for Energy Technologies’ (IEA 2003a)

Policy initiatives designed to facilitate the adoption of cleaner energy technologies should combine three basic priorities:

- Invest in niche markets and learning, in order to improve technology cost and performance;
- Remove or reduce barriers to market development that are based on instances of market failure;
- Use market transformation techniques that address stakeholders’ concerns in adopting new technologies and help to overcome market inertia that can inhibit the take-up of new technologies.

Specific points, based on case studies for a number of technologies and countries, include:

- Deployment policy and programmes are critical for the rapid development of cleaner, more sustainable energy technologies and markets. While technology and market development is driven by the private sector, government has a key role to play in sending clear signals to the market about the public good outcomes it wishes to achieve.
- Programmes to assist in building new markets and transforming existing markets must engage stakeholders. Policy designers must understand the interests of those involved in the market concerned, and there must be clear and continuous two-way communication between policy designers and all stakeholders. This requires assignment of adequate priorities and resources for this function by governments wishing to develop successful deployment initiatives.
- Programmes must dare to set targets that take account of learning effects, i.e. go beyond what stakeholders consider is possible with present alternatives.
- The measures that make up a programme must be coherent and harmonised, both among themselves and with policies for industrial development, environmental control, taxation and other areas of government activity.
- Programmes should stimulate learning investments from private sources and contain procedures for phasing out government subsidies as technology improves and is adopted by the market.

The report concludes that it is the combined effect of technology potential and customer acceptance that makes an impact on markets and hence on energy systems. Developing a deeper understanding of both, including how they are influenced by government, is an essential ingredient of effective technology development and deployment policy.

3.6 Summary

This Section has set out a theoretical framework for assessing energy innovation systems, in order to identify innovation barriers, failures and gaps, and highlighted generic innovation policy implications. The principles and priorities outlined above are revisited in Section 5, in the context of Australian energy policy. However before it is possible to assess innovation in the Australian context it is important to explore the relationship between innovation policies and private sector investment, and between policy design and investment risk.

4 Key factors relating to investment decisions in energy sectors

Innovation policies have a strong requirement for private sector investment. In many cases, policy needs to bring forward technologies that would not otherwise be chosen by liberalised markets. Potential investors need to take a range of risks into account, including price and revenue risks that may be differentiated by technology.

In some cases, technologies that appear competitive or low risk in terms of costs may be an unattractive investment proposition because of revenue risks. In addition, private sector players will factor in a range of strategic issues, including option and portfolio values, the value of waiting for potential to 'game' market participants and policymakers or 'PR' value. This section explains the implications of a range of investment risks for policy, and how policy design in turn affects investment risk.

4.1 Introduction

Section 3 illustrates the range of policy options and policy issues that occur at different stages of the 'innovation chain'. A key finding is that innovation in the low carbon arena is particularly dependent upon policies that can create early markets for emerging technologies. As Section 2 explains, this is particularly important for technologies that have the potential to replace incumbent technologies that are subject to 'lock-in'. Yet as is explored in more detail below, under conditions of market liberalisation and private sector ownership, such policies will only work if they provide a climate that is favourable to investment. In part, this is a product of financial support and/or the removal of barriers to development. Investment risk is also affected by a range of other factors, however. This section introduces some key issues related to policy, investment and risk, based upon a recent report for the UK Energy Research Centre (UKERC) (Gross et al 2007).

The section provides an overview of some of the principles relating investment, risk and policy, explains why these matter to low carbon objectives, particularly where policies seek to promote innovation. Sections 4.2 – 4.5 provide a summary of principles, whilst section 4.6 provides a summary of the key points. In explaining the principles at play, the section focuses primarily on electricity generation.

4.2 Why investment decisions matter

Climate policy goals often require private investors to make investments in technologies that are different from those that they would select in the absence of climate change related interventions. An obvious example in the Australian context would be policies to encourage power generation from renewables rather than coal fired power stations, or to encourage the development of carbon capture and storage technologies. Private investment matters because in many electricity and gas markets around the world, including Australia, privatisation and liberalisation have reduced the influence of policy over investment decisions relative to the days of central planning by state owned utilities (PIU 2002). Instead of state owned corporations pursuing policy goals, investment decisions are made by private companies seeking to maximise return on investment, subject to acceptable levels of risk and within a range of regulatory constraints.

In most countries, recent policy developments are intended to influence the *direction* of investment in energy markets. Some, such as the UK Renewables Obligation (RO), Australian Mandatory Renewable Energy Target (MRET) or the German 'EEG' (Erneuerbare Energien Gesetz) (feed in tariff) seek to direct investment in a highly specific way, directly incentivising renewable sources of energy. Other policies seek to shape the *overall* direction of investment, but in a less specific way, a prominent example being the EU carbon emissions trading scheme (EU ETS). Unless policies encourage or facilitate investment effectively they will not deliver their objectives. For reasons explained in more detail below, the specifics of policy design are relevant to investors and some policy types (or approaches to implementation) are more ‘investor friendly’ than others.

It is also important to take stock of the analytical tools used by governments when deciding not just *whether,* but *how* to intervene in electricity markets. Policy decisions on power generation (for example) are often informed by estimates of cost per unit of output (e.g. £/MWh) or ‘*levelised cost*’[8] which are widely reported in national government, IEA and other studies[9]. Cost estimates may be helpful in informing governments which technologies it may be in the national interest to adopt, and are often used to provide a ‘ballpark’ guide to the levels of subsidy needed (if any) to encourage uptake of different technologies. However, the private companies making the investments will also take into account a range of other factors that are not captured well, or at all, in levelised cost data. These include revenue risks created by electricity price volatility and a range of strategic commercial considerations that may affect both the timing and the nature of investment decisions.

If some of the factors that affect real investment decisions are overlooked or underestimated then a cost focused approach to policy design may lead to ineffective policies. The policy importance of this should not be underestimated. For example in 2006 the UK government was explicit in its contention that the economics of nuclear power ‘look more positive’. This conclusion is based upon an analysis of the relative levelised *costs* of nuclear power and other options under a range of fuel price, carbon price and capital cost scenarios developed for the 2006 Energy Review.

Indeed the British government’s current view (autumn 2007), is that nuclear power does not need financial support, given the long term continuation of the EU ETS (DTI 2007b). The Department of Trade and Industry (DTI, now renamed Department for Business, Enterprise and Regulatory Reform, BERR) explicitly avoided an assessment of the financial proposition offered by new nuclear, stating that would be

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[8] Levelised costs attempt to capture the full lifetime costs of an electricity generating installation, and allocate those costs over the lifetime electrical output, with both future costs and output discounted to present values.

[9] Examples include: the ‘Projected Costs of Generating Electricity’ series of IEA reports, published in 1983, 1986, 1989, 1998 and 2005; UK government White Papers and reports including the 2000 Renewables Obligation Consultation document, the 2002 Energy Review and 2003 Energy White Paper, and the 2006 Energy Review; and the US Department of Energy’s ‘Annual Energy Outlook’ series.

for private investors to consider (DTI 2006a). Yet investment analysis suggests that other commercial factors are likely to militate against investment in nuclear (similar considerations apply to CCS and renewables). Indeed, even if levelised costs were slightly *lower* than those of gas, investment might still be unattractive (Gross et al 2007). The next section seeks to explain why.

4.3 Risk and investment decisions

This section considers the role of different sources of risk in investment appraisal. In competitive markets investment decisions are made in the light of risks and prospective returns to investment[10]. Risk is therefore an important component of investment decision-making. Project risks arise from many sources (see e.g. IEA 2003c). These range from the general (e.g. macro-economic, political and *force majeur* risks) to the more project-specific (see Table 4.1).

Table 4.1: Risks directly affecting a company's cash-flow calculation

	Price Risks	**Technical Risks**	**Financial Risks**
Costs	Fuel price CO_2 price	Capital cost Operating and maintenance cost Decommissioning and waste Regulation	Weighted cost of capital Credit risk
Revenues	Electricity price	Utilisation levels (and timing of utilisation, which can be important for price) Build time	Contractual risk

Revenue and price risks

These risk factors affect different technologies in different ways. They may lead to a re-ordering of the relative attractiveness of the various investment options facing a generation company compared to a more static analysis that does not include risk, since all else being equal companies would prefer to invest in lower risk technologies (IEA 2003b). Each category of risk can vary by technology. Many analyses focus on technology risks, but returns depend on revenues as well as cost, so the *price* of

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[10] *Defining risk:* Different studies use different definitions of risk. Some aim to distinguish between uncertainty and risk, by ascribing the term uncertainty to a situation where it is not possible to parameterise the variability of outcomes, and using risk when outcomes are variable within some expected probability distribution which can be parameterised. In this report, the term 'risk' is used in a more general sense to mean a factor that creates uncertainty in the financial returns of an investment.

electricity becomes an important risk factor in the investment decision. Although all generation technologies within a given market are subject to largely the same time of day price of electricity[11], the level of *exposure* to this price risk varies considerably between generating technologies. As a result, electricity price risk turns out to be an important risk factor affecting technology choice in investment appraisal, and can affect the way an investment is financed and therefore the cost of capital. This section explains why price risk exposure is different for different technologies.

The origins of price risks in competitive markets

If electricity prices were fixed or extremely stable then it would be possible to capture many of the issues in Table 4.1 using levelised costs and the various simulation models used historically by monopoly utilities to optimise investment and operation (see Gross et al 2007). Under monopoly conditions many of these risks could be passed through to consumers. However in countries where electricity prices are not fixed or insulated from risk, levelised costs cannot capture electricity price risks. Price risks arise because of uncertainties about future prices for electricity. These in turn arise for a range of reasons, from large scale economic events or political changes, to volatility in fuel prices or problems with power stations. To understand the implications of price uncertainty and fluctuation for investors, it is first necessary to understand how wholesale electricity prices are formed, and what sets them.

Price formation under liberalised markets

Market structures under liberalised markets differ between countries and are subject to change over time, either as a result of regulatory changes or through merger, consolidation or new market entrants. Markets may be highly competitive, with many companies competing within separate functions (e.g. generation, supply, distribution) or dominated by an oligopoly (or even monopoly) of vertically integrated generation and supply companies. In Britain electricity is bought and sold under a complex set of regulatory arrangements known as BETTA (British Electricity Trading and Transmission Arrangements)[12]. The arrangements result in bilateral trading of large volumes of energy between suppliers and generators, and much smaller trades closer to real time through power exchanges and the balancing mechanism. The Australian arrangements are somewhat different, taking the form of an electricity pool in the regions covered by the National Electricity Market (NEM), and primarily state government operation of the systems outside these regions.

In all cases electricity prices include a ‘time of day’ component, since generation must be increased and decreased as demands fluctuate on an hourly and diurnal basis as well as over longer timeframes. The result of this is that depending on precise trading arrangements the market, or the system operator, determines the ‘dispatch’ of plants according to short run marginal cost, and the spot price of electricity at any given time of day is set by the short-run marginal cost of the last generator to be dispatched (i.e. the most expensive) at that time on the system. These are the system marginal plant,

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[11] Some generators may receive additional payments for the provision electricity system services, based on contracts issued (in the UK) by the System Operator see http://www.nationalgrid.com/uk/Electricity/Codes/systemcode/contracts/

[12] The operation of this mechanism is not described in detail here. For a brief overview see http://www.ofgem.gov.uk/temp/ofgem/cache/cmsattach/10081_2605.pdf?wtfrom=/ofgem/work/index.jsp&section=/areasofwork/betta/betta02

and for that particular time of day will set the price of electricity (i.e. acting as *price makers*) and all other plant on the system will be *price takers*.

Short-run marginal costs include all variable costs, including fuel costs, variable operating and maintenance costs, CO_2 and other environmental costs borne by the electricity producer. They exclude fixed costs such as capital depreciation and fixed operating and maintenance costs. Hence, the lowest short run marginal cost plants are used first, and most of the time. Such plants, often referred to as ‘baseload’ generators, are usually high capital cost but low or zero fuel cost technologies. In systems with nuclear, hydro and renewables available these will usually be dispatched first. The newest and most efficient fossil fuel plants will also run on baseload, particularly in largely fossil fired systems such as that of Australia. Fuel prices and plant efficiencies for the system marginal plant(s) determine the short run price of wholesale electricity. This also implies that fuel price volatility is reflected in wholesale electricity prices and indeed fuel price increases are eventually passed through to consumers. Hence, to an extent, price making fossil fuel generators have a degree of natural ‘hedge’ against fuel price fluctuations because changes in fuel prices are reflected in changes to electricity prices.

One effect of the way that markets order the ‘dispatch’ of plant according to marginal cost has been to reverse the relative utilisation of coal and gas fired power in Britain and other countries in the period since oil and gas prices began to increase in around 2003. Whereas gas was once utilised immediately ‘above’ nuclear and renewables, with many CCGTs on baseload, now coal fulfils that role, and whilst coal used to ‘load follow’ now gas fulfils that role. Regardless of the utilisation of coal or gas, high fixed cost and low/zero fuel cost plant such as nuclear power and renewables are almost always price takers. They are highly unlikely to be marginal plant[13], and always take the prices set by plant that are marginal. Hence they benefit when prices are relatively high (as gas and electricity prices were during 2006), but may suffer when prices are low (for example during 2001). In what follows, the significance of this is explained for the ranges of cash flows that might be calculated for three of the main types of electricity generation – coal, gas and nuclear power[14], compared to the ranges of levelised costs for these generators.

The implications of price uncertainty for investment are explored in detail in a UKERC Working Paper (Blyth 2006), which is summarised here. Figure 4.1 reproduces the levelised cost figures from the Energy Review for gas (CCGT), coal (PF coal plus FGD), and nuclear (pressurised water reactor). The low and high cases for coal and nuclear refer to the more favourable and less favourable technology assumptions used in the Review respectively. The ranges for gas and coal relate to the maximum and minimum levelised costs for the different fuel price and carbon price scenarios used in the Energy Review. The fuel price scenarios include two central scenarios (one favourable to coal, one favourable to gas), plus a high fuel price and a low fuel price scenario. There are four CO_2 price scenarios, £0/tCO_2, £10/tCO_2, £17/tCO_2, and £25/tCO_2.

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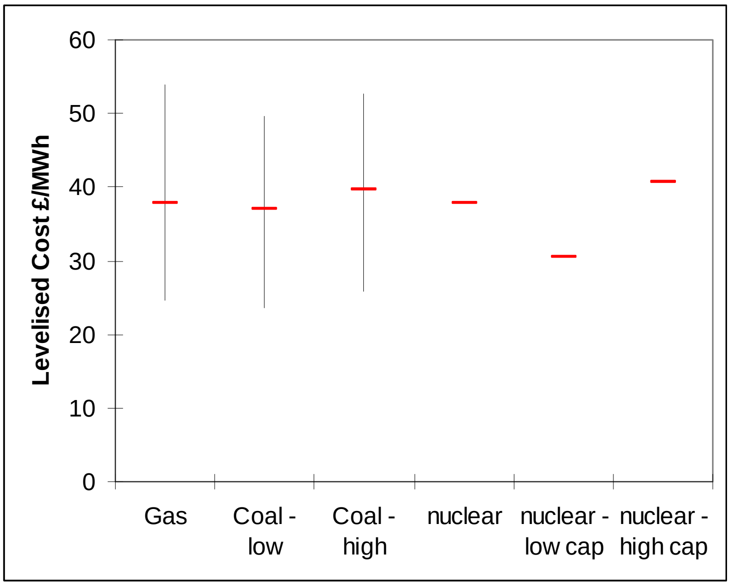
[13] This is a generalisation relevant to systems with a mix of fossil and non-fossil plant. Different conditions may apply in systems with very high penetrations of high capital low fuel cost technologies e.g. nuclear power in France or hydro in Norway.

[14] Note that the factors relevant to nuclear power would also apply to wind, hydro and other renewables, except biomass plant, which might be regarded as more akin to a fossil fuel generator.

Figure 4.1: Spread in levelised costs arising from different CO_2 and fuel price scenarios taken from DTI 2006c from Gross et al 2007



The levelised cost representation simply represents the costs of generation, and does not consider the revenue side of the equation. This has the potential to be rather misleading with regard to the relative attractiveness for investors of each of the three options. For example, it would be easy to misinterpret the lack of any spread in the levelised costs for nuclear plant as indicating that the investment case for nuclear generation is independent of fuel and CO_2 price risk. In fact, whilst these prices do not affect the *costs* of generation for nuclear, and therefore do not show up in the levelised cost representation, nuclear plant, like other price takers, is exposed to revenue risk resulting from electricity price fluctuations.

The implications of electricity price risk for cash flow and hence investors can be assessed by incorporating both costs and revenues into a full discounted cash flow calculation. This requires some assumptions to be made about the electricity price formation process. For illustrative purposes, the technical information and price scenarios were again taken from the Energy Review (DTI 2006c), and put into a simple cash-flow model. This assumed that either coal or gas plant would be on the margin of the electricity system depending on the fuel and CO_2 price in any given year under each scenario. The efficiency of the marginal gas plant was taken to be 40%, and the efficiency of the marginal coal plant was taken to be 30%. Standard emission factors for each type of fuel were applied to calculate the rate at which a given CO_2 price would be passed through to the price of a kWh of electricity (assuming 100% pass through of costs independent of the allocation mechanism).

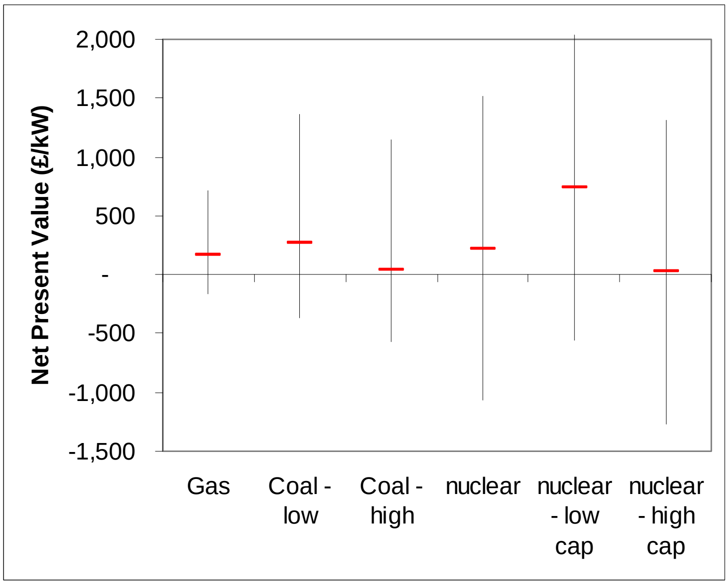
These assumptions are rather crude and arbitrary, and companies will generally incorporate much more sophisticated analysis than this when modelling revenue risk for a new project. However this illustrates the basic approach.

The results are shown in Figure 4.2. This essentially takes the same projects shown in Figure 4.1, but instead of giving the levelised costs, it shows the net present value (NPV) of the different projects, expressed per kW of capacity of the plant. NPV is the product of:

1. The present value of the expected output of the plant times the market price of output over the lifetime of the plant, minus
2. The present value of the capital costs of the plant, plus the annual maintenance costs, plus the output of the plant times its fuel and other variable costs.

The advantage of the NPV approach is that it represents the range of potential financial outcomes for each of the technologies on the same terms, and in the same units that matter to financial backers[15].

Figure 4.2: Net present value representation of the spread of returns arising from different CO_2 and fuel price scenarios taken from DTI 2006c



The range of NPVs illustrated in Figure 4.2 provides a simplified indication of a spread of possible returns, hence risks. In reality any investment proposition will be further complicated by a range of other factors that affect the cost of capital and hurdle rate. These may reflect, for example, the size of investment, timescales and qualitative factors.

The discussion above focuses on how short run (diurnal or seasonal) prices are set by marginal cost plant. However, electricity markets are also subject to price volatility over longer time horizons, typically periods of several years of higher or lower average prices. Such variations may be the product of fuel price movements, regulatory change, industry restructuring (for example new market entrants or consolidation activity) and the relationship between demand and available plant capacity. Figure 4.3 provides a stylised graphical representation. Volatility is a key source of risk for investors in capital intensive power plants. It can restrict the amount of debt finance that can be secured for such plants, since debt will need to be covered even in periods of very low prices, which increases the cost of capital faced by prospective developers (see Gross et al 2007) for a more detailed discussion).

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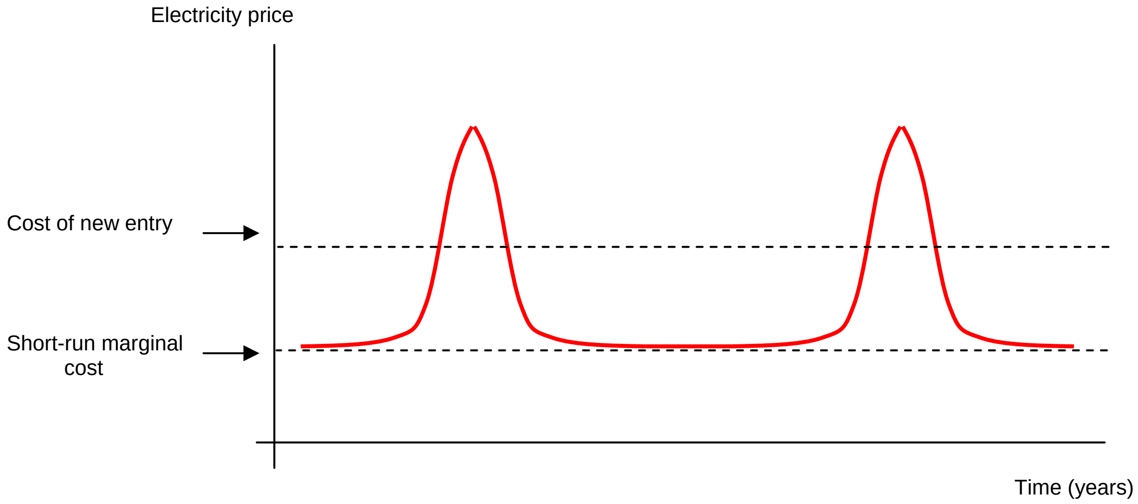
[15] The y-axis is related to the profit per MW that could be achieved from the projects, for illustrative purposes this is expressed neglecting the effects of tax.

Figure 4.3 Investment and price cycles in a competitive market



The principal point to note from the analysis above is that investment risks and cost risks are not one and the same thing in competitive markets. Plants that cannot affect market prices are exposed to a revenue risk that has little to do with their costs (though of course the higher their fixed costs the greater the risk of a negative net return during periods of low electricity prices).

4.4 Corporate behaviour and risk

The range of NPVs illustrated in Figure 4.2 provides a simplified indication of a spread of possible returns, hence risks. The basic principles of how investors financially appraise investments will be familiar to a wide audience of project development, economic and finance professionals. In simple terms, investors consider the net present value (NPV) and derive the internal rate of return (IRR) of an investment. Risk is represented within an NPV calculation by using a risk-adjusted discount rate. In reality any investment proposition will be further complicated by a range of other factors that affect the cost of capital and hurdle rate. These may reflect, for example, the size of investment, timescales and qualitative factors. Many companies run a detailed model of the electricity system they are considering making an investment into, with major generation plant represented. Such models may be used to assess possible financial outcomes, hence risks, by either generating a set of NPVs from a set of discrete scenarios and/or a by generating a spread of NPVs using a stochastic approach.

A scenario approach would build scenarios which give a forward curve for each of these parameters, such that each scenario leads to a given NPV outcome. The analysis would give a range of NPVs for the project depending on how the project performs under the different scenarios, (see Feretic & Tomsic 2005). A stochastic approach would run the model hundreds or thousands of times, each time picking a different value from within the range for the different uncertain parameters. The model would pick values with a frequency determined by an assumed probability distribution for the uncertain variable. Correlation between different variables would also be taken into account (i.e. so that if a high value of one variable was picked, there would be a greater probability of a high value being picked for another correlated variable). This analysis would give a probability distribution for the NPV, the mean of which would be the expected NPV for the project.

Given a certain risk profile in terms of a spread/range of NPVs, companies will have different ways of assessing the importance of the distribution of potential project returns. They may simply put a value on the down-side risks, and compare these between the various projects available to them to reduce risk exposure. There is an absolute level of down-side risk to which any company can be exposed without damaging its' credit ratings. Alternatively, companies may use the distributions to classify the risk rating of the project, and hence help determine the appropriate hurdle rate to use within an IRR-type approach. This may be most appropriate when considering projects with well-understood risks. It is important to note that the criteria that different investor groups (lenders, equity investors, companies investing 'on balance sheet) will apply to developing and assessing the spread of NPVs will differ.

These factors are too complex to examine in detail here. However Gross et al explore factors such as the share of debt that a project can secure, and how the split between debt and equity differs between technologies[16]. An important conclusion is that the relatively low risk technologies able to secure a large share of debt finance tend to be the conventional market choices, gas fired CCGT in the UK. The higher returns required by equity investors tend to militate against lower carbon options in the absence of additional policies.

Strategic investments

Companies will also have strategic reasons for making particular investments. Whilst the relative importance of strategic factors is dependent on market and industry structures, they can often contribute as much as, or more than, the purely financial considerations. There are a range of strategic factors that effect investment; a few examples are reviewed below.

- *Portfolio effects.* New plant could add value to the company in a way that cannot be captured simply by looking at the finances of the individual project. Portfolio techniques can be used to assess how individual projects add value in addition to their own expected returns, by balancing risks within a broader portfolio of generation types, since different generation types have risk profiles (Awerbuch & Berger 2003; Wiser et al. 2004). Companies will often apply similar concepts in a less formal way by aiming for diversification of their generation portfolio as part of their overall corporate strategy.
- *Competitors.* Strategic considerations relative to competitors may also be important. For example a company may want to break into a new market, or to acquire plant to consolidate market position (which may or may not be linked to a desire to diversify the technology base of its generating portfolio). Such considerations are more likely to become important where the companies active in a market are relatively large, able to put equity directly into particular projects, or

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[16] Techniques also exist to explicitly quantify the effects of different sources of risk based on real option theory (Dixit & Pindyck 1994; Trigeorgis 1996). There is quite a substantial literature developing on the use of these techniques for example (Edelson & Reinhart; EPRI 1999; Frayer & Uludere 2001; IEA 2007; Ishii & Yan 2004; Lambrecht & Perraudin 2003; Laurikka & Koljonen 2006; Reedman et al. 2006; Rothwell 2006; Sekar et al. 2005), but real options techniques are not widely used in a commercial setting and expertise and qualitative perceptions of corporate decision makers play an important role in assessing projects.

where the market is concentrated enough for large companies to seek market power.

- *Timing, gaming and the option to wait.* Companies will need to take a view on the likely timing of new capacity additions being made by their competitors and the potential for policy support by government for particular types of investment. For example, if companies believe that additional policy support is likely to be announced for a particular technology, then there will be a value attached to waiting until the support mechanism is available, and in retaining an option to invest in such technologies. If all (or most) companies decide to wait then additional support becomes more necessary. The potential to 'second guess' the actions of competitors and/or to deliberately manipulate policy has been referred to as 'gaming' – meaning that companies act in order to influence the behaviour of other players as well as assessing an investment or other action on its merits, see (Green & Newbury 1992; Powell 1993; Varian 1992).
- *Intellectual Property.* Investment that builds knowledge or provides information may also have additional strategic value that will feed into the investment decision. This may be important when investing in new technology areas which are expected to be an important part of the future generation mix but which currently have a degree of uncertainty over costs (e.g. offshore wind, nuclear, CCS). Industry contributors to this project suggested that strategic investment considerations such as this may be reflected in the hurdle rate expected of projects. Hurdle rates may be lower for strategic projects and/or more 'relaxed' assumptions may be permitted in the estimation of returns, particularly for relatively small 'pilot' projects.

4.5 Implications for policies influencing investment decisions

The UKERC report on investment decisions recommends that policymakers develop the capacity to actively model investment out-turns, taking price risks into account. The authors continue to interact with UK policymakers on this point.

Another important implication for policy is that policy itself comprises a key *part of* the risk profile of a prospective investment. There are a range of reasons for this, not least because policies can be changed. Policy or regulatory change resulting from a change in government, or other circumstance, is outside the control of project developer or investor. Unlike other more technical risks, these are very difficult to mitigate, yet can undermine revenue streams built into business models, and have a serious impact on projects or firms. Moreover policy design can even create price risks. Some policies will reduce the spread of possible returns whereas others increase them – even when the amount of support (in total or per MWh) is the same.

The discussion that follows is focused upon renewable energy policies, as these are the most widely used revenue support policies currently in play in electricity markets. However, similar principles apply to investment risk created by any emissions trading scheme, such as the EU ETS – see (Blyth 2006). Any new measures aimed at particular technologies, whether low carbon or otherwise, would be subject to the same considerations. This may be important in the Australian context as it will be relevant to measures to promote carbon capture and storage (CCS), which has particular characteristics such as the need for new infrastructure. Policies could be designed in order to provide investor certainty or to allow market mechanisms to reveal costs.

Price risks and policy design, the case of renewables mechanisms

It is possible to identify three ‘levels’ of price risk associated with different forms of revenue support for renewable energy operating in different countries:

1. Fixed prices for renewables output for a fixed period of time (Feed in Tariffs as in use in Germany and many other countries). Payments per MWh are fixed for particular technologies at a particular rate for a particular time period (or number of operating hours).
2. A fixed ‘uplift’ or feed-in premium over and above market electricity prices, again fixed by technology (an option available to wind farm developers in under current Spanish legislation for example).
3. A market exists for renewable energy certificates (The UK RO and the MRET in Australia for example). Such markets may be differentiated by technology or encompass all forms of renewables generation.

The amount of revenue risk that developers are exposed to increases in moving from mechanisms 1 through 2 to 3: In case 1, ‘pure’ feed in tariffs provide a fixed price, and revenue risks associated with electricity price movements are effectively removed from the developer’s investment decision. Whilst in most countries tariff rates are adjusted regularly by regulators, existing projects are ‘grandfathered’ (guaranteed payment at the rate pertaining when the project was commissioned). In case 2, developers are exposed to electricity price movements, although they are guaranteed a minimum payment. However in case 3 developers are exposed to price risks in *both* electricity markets and the market for renewables certificates. For example, the UK RO has no ‘floor’ price on Renewable Obligation Certificates (ROCs) so at least in theory the price for these could fall to low levels, even zero. Prices may also rise in situations of shortage and give low cost generators a ‘windfall’, but this may not in itself mitigate the risk of low or zero ROC prices.

The UK’s Renewables Obligation therefore has greater price risks associated with it than the feed in tariffs common in other parts of Europe. A period of low average electricity prices poses a particular risk for capital intensive investments. A project’s exposure to period of low average prices would be explored as part of investment appraisal. Whilst the ROC price is not bound to electricity prices, it cannot insulate investments from electricity price risks, and ROC prices are themselves uncertain. It should therefore be expected that investors will view low electricity/ROC prices as an added risk, and seek higher returns. Investors may also be more averse to projects which have high technology risks under the RO than they would under fixed tariff arrangements. This is because overall risk exposure will be higher under the RO.

A case study of offshore wind in the UKERC report suggests that the price risks associated with the RO were a factor in the slow progress with investment in offshore wind in Britain relative to experience in Denmark, where a fixed price regime exists for offshore wind. Despite similar costs and *lower* levels of revenue support, Danish developments are largely on track whereas British developments have proceeded more slowly than policymakers intended. It may therefore be that using fixed prices to transfer risk away from developers is likely to be most desirable in instances where technology risks are also high.

The report notes that *there is a ‘risk hierarchy’ linking policy to technology maturity:*

- *Capital subsidies and/or PFI equity stakes are most likely to be appropriate for wholly new technologies emerging from R&D*, and/or for unproven and large scale 'lumpy' investments where there is limited prospect of incremental learning through small scale early commercial units. e.g. CCS and possibly wave power.
- *Fixed price tariff schemes may be most appropriate for development and deployment of emerging technologies;* i.e. those that are demonstrated, but are yet to be used on a large scale, are subject to considerable technology risk and have yet to benefit from extensive 'learning by using'. e.g. offshore wind, also possibly CCS.
- *Market based schemes are generally most suited to proven technologies*, or to incentivise least cost means for short term carbon reduction. e.g. onshore wind.

Underpinning all of the above should be a carbon pricing mechanism, intended to sustain investment and further development in the low carbon technologies as they mature. Policy also needs to take into account a range of strategic actions undertaken by companies. Relevant factors include access to cost data (companies may have better data than policymakers), the option value attached to 'waiting' (for additional policy support or for competitors to reveal costs) and so called 'appraisal optimism' leading companies to underestimate costs for new technologies. These latter two points may lead companies to provide policymakers with underestimates of costs and may be contrasted with the policymaker 'conventional wisdom' that companies inflate costs in order to secure more generous premium payments.

The implications of appraisal optimism, poor information and misrepresentation of costs are as follows:

- Policymakers may have relatively poor information about costs for emerging technologies, since unlike the pre-liberalised central planners who purchased or developed technologies they are not able to secure such information 'first hand'.
- 'Appraisal optimism' is a common feature in the development of new technologies. Technology developers or equipment suppliers may also have incentives to play up or play down costs and potential according to circumstance.
- Where new or unproven technologies are being utilised for the first time, information about costs may be limited for all concerned.
- Costs (and the accuracy of ex ante estimates) will be revealed primarily through market actions.
- There may be an 'option value' for potential investors in waiting (delaying investment) where there is poor information and high levels of technology and market risk.
- Policy may need to recompense at least to the option value of waiting, as well as the (high initial) cost of the technology and both technology and market risk. Policy will also need to take account of appraisal optimism and the interests of market participants. ' Hence;
- 'Over-remuneration' relative to levelised cost estimates may be needed for early stage or unproven technologies.

The UKERC case study of British and Danish experience with offshore wind concludes that whilst both countries would have been subject to appraisal optimism and cost out-turns have indeed been higher than anticipated in studies from both sides of the North Sea, the additional risks imposed by the RO have hindered the development of British farms (Gross et al 2007). Moreover it appears that the Danish developments are able to deliver electricity at lower unit costs than largely similar developments in Britain, despite similar capital costs. This is partially due to load factor differentials but also indicates that the Danish (fixed price) scheme of revenue support has allowed developers to secure investment at lower costs of capital. It appears that in the case of offshore wind in the UK, costs and risks (including risks created by the Renewables Obligation itself) were underestimated and hence policies put in place could not deliver the levels of investment desired by the government.

4.6 Summary

- Cost estimates have played a central role in the formulation of policy instruments. They help indicate the cost of meeting public policy objectives such as reducing CO_2 emissions, and/or whether there is therefore a rationale for such support (for example based on cost effectiveness or net welfare gains). They give an initial indication of the scale of support required for particular technologies, and cost projections may be used to assess the value of support for innovation.

- Cost estimates have limitations, however, in part because there is a range of plausible estimates for any given technology and market/operating assumptions. Moreover, under liberalised markets investment is driven by expected returns, which are assessed in the light of a range of risks related to both costs and *revenues*. An important category of revenue risks are associated with electricity price fluctuations. These risks cannot be captured in levelised cost figures.

- In some cases, technologies that appear competitive or low risk in terms of costs may be an unattractive investment proposition because of revenue risks. If price risks are large then the spread of returns to investment for a given technology may be much wider than the range of levelised cost estimates for that option.

- Exposure to price risks differs by technology because some options (usually fossil fuel generators) act as ‘price makers’. This means they are able to influence system prices and can also pass fuel cost fluctuations through to consumers. As a result, even if fuel and power prices are uncertain, returns on investment are relatively secure. Others, so called ‘price takers’ (nuclear, renewable and hydro plants), have high fixed costs but little or no control over system prices. Price takers benefit when electricity prices are high, but during a period of sustained low prices they may be unable to cover their fixed costs. If prices are volatile then revenue risks are higher for the latter class of technologies, which may discourage investment irrespective of their relative costs.

- In practice, the extent of electricity price volatility, hence price risk, is a function of market conditions and structure. The UK market has experienced considerable volatility in recent years, and the margin between fossil fuel and electricity prices has tended to be low. This typically favours low risk investments that can secure a high debt/equity ratio (currently gas-fired generation in the UK).

- In addition to assessment of risk and return, investment decisions will also be affected by a range of strategic considerations. These include portfolio effects, market share considerations and PR benefits. Investment may be undertaken to reveal information or gain market advantage, and it may be delayed for the same reasons. 'Option value' captures these issues. In the case of new technologies or where new policies are expected, option value may be attached to waiting.

- Policy may need to recompense at least to the option value of waiting, as well as the (high initial) cost of the technology and both technology and market risk. Policy will also need to take account of appraisal optimism and the interests of market participants. 'Over-remuneration' relative to levelised cost estimates may be needed for early stage or unproven technologies.
- Policy needs to actively engage with investment risk. This means understanding where risk originates and how it affects investment. Policy analysis needs to actively model investment scenarios and incorporate revenue risk, rather than focusing largely on costs.
- Policy design can affect price risks. The choice between fixed price tariffs and market-based schemes is a choice about risk allocation. Policy-makers need to make judgements about types of risks are and who is in the best position to handle them. For example, fixed price schemes or price 'floors' reduce or remove the risks associated with electricity prices falling below a level sufficient to sustain debt servicing. They may, however, expose consumers to greater risks in terms of an uncertain level of total expenditure, and may fail to incentivise developers to reveal true costs. Market schemes allocate more risk to the developer and could provide greater competitive pressure to reduce costs, but if the risks are too large, the market may simply fail to deliver the investment needed for learning. *Hence there is a 'risk hierarchy' linking policy to technology maturity:*
    - *Capital subsidies and/or PFI equity stakes are most likely to be appropriate for wholly new technologies emerging from R&D*, and/or for unproven and large scale 'lumpy' investments where there is limited prospect of incremental learning through small scale early commercial units, e.g. CCS and possibly wave power.
    - *Fixed price tariff schemes may be most appropriate for initial roll out of emerging technologies;* i.e. those demonstrated, but yet to be used on a large scale, that are subject to considerable technology risk and have yet to benefit from extensive 'learning by using', e.g. offshore wind and possibly CCS.
    - *Market based schemes are generally most suited to proven technologies*, or to incentivise least cost means for short term carbon reduction, e.g. onshore wind.
    - *Policies that are designed to support investment in high risk, early stage options will be most effective if in addition to providing remuneration they also seek to reduce or remove revenue risks associated with price volatility.* Very early stage options may benefit from capital subsidies, as these can also mitigate technology risks.

Underpinning such measures should be a carbon pricing mechanism, to sustain investment and further development in low carbon technologies as they mature.

The relationship between innovation systems, investment risk and policy in the Australian context is complex, requiring considerable additional research. The next section assesses the key issues and provides an indication of the areas where further work might be able to enhance the effectiveness of Australian innovation policies, taking account of the investment principles outlined above.

5 Issues for low carbon innovation policy in Australia

Low carbon innovation policies in Australia already exist. However, further research could do more to assess additional policy options to enhance the development of low carbon technologies such as CCS, renewables and decentralised generation.

This section explores these issues in detail, finding that an innovation systems perspective can help to identify potential gaps in existing Australian policies, and providing a framework against which potential future policies can be assessed. Innovation systems can help with choosing the right mix of policies to support R&D, demonstration and commercial exploitation. This mix must also factor in the effects of investment risks. An innovation systems approach also highlights the importance of a long term strategic framework, including a price for carbon emissions, within which more targeted innovation policies are based.

5.1 Introduction

This section considers the implications of issues related to innovation systems and investment risk for Australian innovation policy. The authors are not able to provide detailed commentary on the Australian policy landscape, so the section attempts to highlight areas where more detailed analyses of innovation systems and policies in Australia could inform subsequent policy, based on findings from UK-based analyses of innovation systems and investment risk (outlined in sections 3 and 4). Much of the analysis focuses on issues and technologies that apply in the electricity sector, but similar issues apply with regard to the provision of heat, in energy efficiency, and that related issues apply in the transport arena[17].

'Guiding Principles'

The innovation systems approach highlights the systemic interactions, bounded rationality of actors and the importance of institutional set-ups, and provides high-level insights rather than detailed policy recommendations. Some key points from these 'guiding principles' (Foxon et al 2005b) and their application to low carbon innovation policy (Foxon & Pearson 2007) are summarised here.

Firstly, innovation systems analysis suggests that it is important to create a long-term, stable and consistent strategic framework to promote a transition to a low carbon economy. This would aim to create a positive climate for investment in a diverse range of technologies. One of the lessons from UK experience has been that the policies have not always been designed in a way that is as consistent with promoting

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[17] See http://www.dft.gov.uk/pgr/scienceresearch/technology/lctis/lowcarbontis for application of innovation systems thinking to the UK transport sector and http://www.hm-treasury.gov.uk/pre_budget_report/prebud_pbr05/other_docs/prebud_pbr05_odenergy.cfm for application to energy efficiency.

innovation and securing investment. The key aim should be to ensure that steps towards achieving long-term systemic changes in technological systems are put in place alongside measures to deliver emissions reductions in the short and medium term. This report recommends that the Garnaut Review analyses the extent to which current policies in Australia form a coherent low carbon innovation policy regime.

Secondly, although it entails a degree of simplification, the ‘innovation chain’ can help identify policies that are appropriate for technologies at different stages of development. The authors’ analysis of UK renewables innovation systems led to the identification of ‘systems failures’ in bringing early stage renewable technologies along the innovation chain towards commercialisation. The Garnaut Review may find that it is helpful to undertake further analyses of whether similar ‘systems failures’ are occurring in Australian innovation systems for renewables, and whether or not proposed policies to support carbon capture and storage (CCS) technologies would be likely to experience similar difficulties. Policy issues related to CCS and renewables are discussed in Section 5.3, below.

Thirdly, it is important to enable learning to occur in policy processes. Just as it is not clear ahead of time which particular technology options will be successful, it may not be clear ahead of time which is the best mix of policy measures to apply, so the ability to retain a degree of flexibility and adaptability within a clear long-term strategic framework is important.

Some practical examples of the relationship between these principles and Australian energy policy are discussed in Section 5.4. By way of background to inform the discussion, Sections 5.2 and 5.3 provide a brief review of the policy and energy system context.

Practical considerations on costs and commitment

It has also become clear from a large number of studies and from policy experience so far that in all likelihood there will be significant costs entailed in moving to a low carbon energy system—and hence that significant price and regulatory incentives will be needed in the form of carbon pricing and incentives for innovation. Figure 5.1 taken from the Stern Review summarises the point.[18] It shows the estimated global average costs of CO2 abatement (the costs are based on ppp exchange rates, given the dollar’s currently low level), which are expected to decline over time with innovation. The red dashed lines show the range of possibilities, the upper dashed line corresponding to low rates of innovation and low world oil and gas prices, and the lower dashed line to high rates of innovation and high world oil and gas prices. It is possible, on a more buoyant scenario of innovation and tightening world markets for oil and gas that the costs of a transition to a low carbon system may become negative—but we cannot gamble on this. The likelihood is that the costs will be significant and significant incentives will need to be in place for some time; experience in the EU, the UK and the US (summarised in section 2.4 above) has proven this, as has the case of Japan, who have likewise provided significant incentives.

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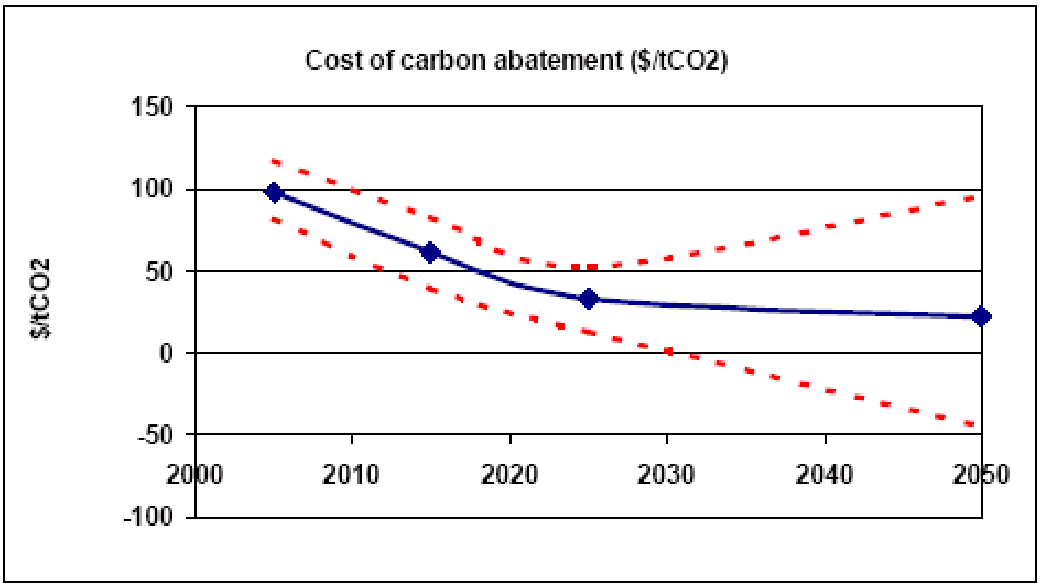
[18] The technical details and cost assumptions under-pinning this figure are in the background paper by Anderson (2006), which is on the Treasury website for the Stern Review.

Figure 5.1. Potential costs of carbon abatement to 2050 (Stern 2006)



Note: since the figure shows average not marginal costs it is not appropriate for estimating the optimal price incentives. Marginal costs are in general higher.

It is worth recalling that, despite the seemingly high costs shown in Figure 5.1, the Stern Review showed that, in aggregate, they amount to a small percentage of GDP and its growth—rising to about 1% with a range -1.5 to +3.5% of annual GDP over the next 50 years, in economies where GDPs are likely to rise by 100-200% over the same period. Large as they are in absolute terms, there is no evidence that the costs of a transition to a low carbon system will be disruptive to economic growth—quite the opposite once the benefits of carbon abatement are taken into account.

It should be emphasised that estimates of costs differ between countries for the obvious reason that their energy resource endowments differ, in the renewable energy sector as in fossil fuels. Methods of estimating average costs are to be found in Anderson (2006 and 2007, the latter being a study for the UK).

For estimating the price incentives required, the familiar methods of levelised and marginal cost analysis can be used; but a step forward would be to use the rate-of-return methods discussed in Section 4, which provide a better indication of how the private sector will respond to price incentives and a better understanding of risks.

5.2 Review of the Australian energy system

Resources

Australia has abundant reserves of low cost coal and is the world's largest coal exporter. Gas and renewable resources (including solar, wind, geothermal and biomass) are also 'very large' (Australian Business Council for Sustainable Energy 2007). Nevertheless, the current primary energy consumption mix is dominated by coal (with 41% share) oil (35%) and natural gas (19%), with renewables currently forming just 5% of primary energy consumption.

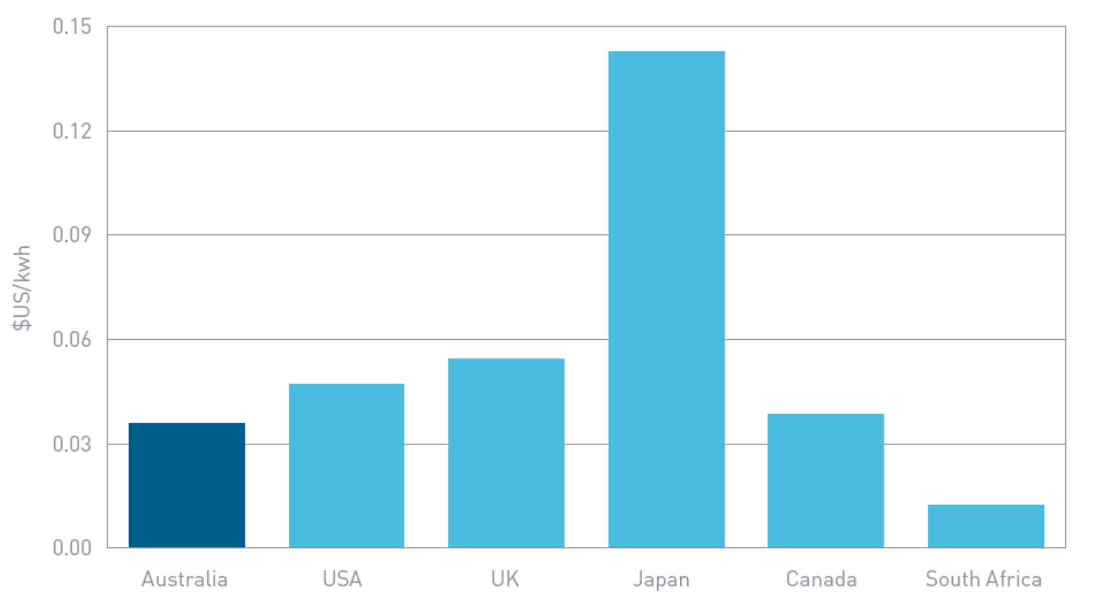
The fuel mix for electricity generation is dominated by coal - of total annual electricity production of a little over 220TWh (2005/6), 83.8% was coal-fired, 8.5%

from gas-fired generation, and 7.3% from hydropower schemes. The remainder is made up from oil (0.15%), wind (0.14%), and other sources (Energy Supply Association of Australia Limited 2007). This contrasts markedly with the UK electricity mix, which has a much larger share of gas fired generation (around 40%), with around 20% of electricity from nuclear, 4% from renewables and the remainder largely coal (also import from France, and modest amounts of hydro and oil fired generation) (DTI 2007a). British generators supply around 400 TWh/yr, and demand growth in Britain is considerably lower than in Australia, reflecting industrial, economic and demographic differences as well as UK energy efficiency policies (DTI 2007a) (Energy Supply Association of Australia Limited 2007).

Electricity prices

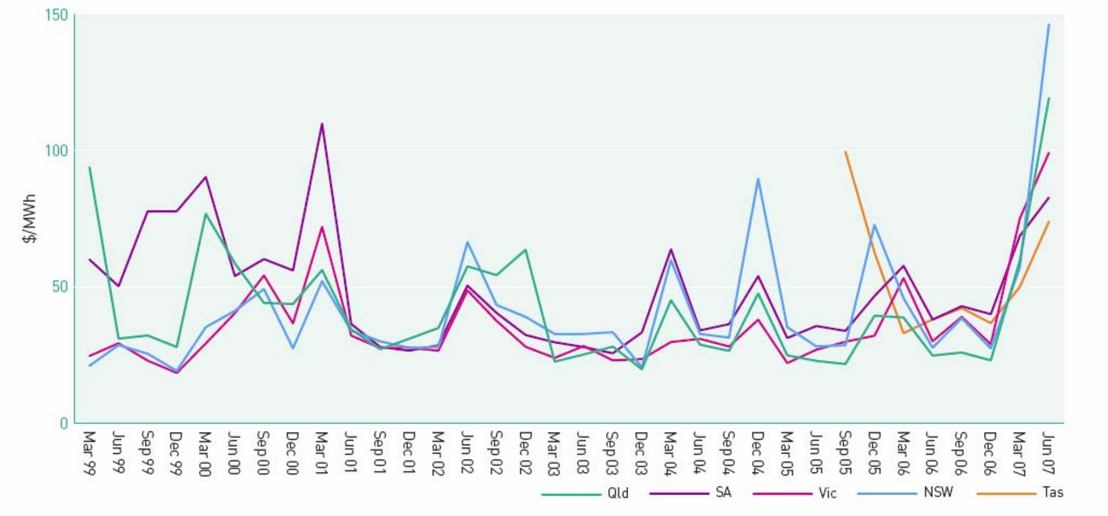
Australian electricity prices are low in comparison with other countries, indeed as illustrated in Figure 5.2 below, Australia has some of the lowest electricity prices in the developed world. Whilst this may provide competitive advantage to the Australian economy, it also has potentially important implications for the penetration of CO_2-reducing technologies into the electricity market. These implications are discussed in section 5.4.

Figure 5.2 Industrial Electricity Prices Q4, 2002 (Energy Task Force 2004)



The analysis in section 4 illustrated the importance of electricity price volatility when assessing generation investment risk. Figure 5.3 plots the movement of spot prices in the NEM pools since liberalisation of Australian electricity markets and shows that prices exhibit significant volatility. Prices in other liberalised markets such as the UK show similar or greater volatility – although the underlying reasons may differ from one market to another.

Figure 5.3 Quarterly volume-weighted average spot price the NEM pools (Australian Energy Regulator 2007)



Market Structure

The Australian electricity industry is characterised by a mix of public (state governments) and private ownership, and a combination of interconnected control areas and separate systems for supplying isolated centres of demand. A mix of public and private ownership structures exists throughout all sections of the electricity industry, from generation, through transmission and distribution services, to retail activities. Trading of electricity in the interconnected areas is administered by the National Electricity Market Management Company (NEMMCO) through a pool system where generators submit bids for the supply of electricity and generation is then dispatched on a least-cost-first merit order (subject to transmission and other operational constraints). The price paid to all dispatched generators in each regional pool in any given half hour trading period is set by the marginal plant i.e. the last plant dispatched in the merit order. (NEMMCO 2005)

Whilst Western Australia and the Northern Territory (the areas not covered by NEMMCO) have their own arrangements for operating their respective electricity systems, one particular characteristic is the large number of isolated centres of demand with no connection to a larger transmission grid. Practical limitations effectively rule out the possibility of competing generators on small, isolated systems and integrating intermittent renewables into small, isolated systems is relatively more difficult than integrating them into large, interconnected systems (Gross et al. 2006).

Implications

Given a situation so favourable to fossil fuels, particularly coal, the challenge for Australian policymakers is to provide measures which can encourage investment in anything other then conventional coal and gas. The next section provides an overview of current Australian low carbon and renewable energy policies, before moving on to explore some of the potential implications of the principles outlined in Sections 1-4 for the Australian context.

5.3 Australian low carbon policies

Mandatory Renewable Energy Target (MRET)

The MRET creates a rising target for renewables to 2010 by which time it is intended that 9,500 GWh of electricity will be supplied from qualifying renewable sources. This is equivalent to approximately one twenty-fifth (4%) of total 2005/6 electricity production. The MRET operates in a broadly similar manner to the UK Renewables Obligation (RO) and has suffered some of the same type of criticism levelled at the RO (see Section 4) and (NAO 2005). The Australian Federal Government has decided that the MRET will remain at the 2010 level from then until 2020, when the scheme comes to an end.

Technology development policies

Whilst the MRET will continue until 2020, the 2004 Energy White Paper signalled a shift in focus to a package of direct support for technology development (Energy Task Force 2004):

- A $500m Low Emissions Technology Demonstration Fund (LETDF) – aimed at industry-led commercial demonstration stage technologies which could make substantive reductions in CO_2 emissions, and where Australia could establish a competitive advantage and/or develop capabilities which are closely matched to Australian circumstances. The Fund is ‘technology neutral’ and energy efficiency, stationary energy and transport energy are all eligible. It is intended to ‘fill the funding gap in the technology innovation chain between R&D and commercial uptake’ (Department of the Environment and Heritage and the Department of Industry 2005). In addition there is a $100m fund to support the development of smaller scale renewable energy technologies.
- $75m ‘Solar Cities’ trials - these are intended to demonstrate how a combination of solar energy technologies, energy efficiency, and efficient energy markets can deliver sustainability. A particular objective of this initiative is to address how the characteristics of solar technologies (in particular photovoltaics) could be appropriately rewarded by energy markets – if for example, electricity markets do not allow the full value of photovoltaics to be captured then this would have important implications for investment in such technologies.
- An $18m fund to support the development and demonstration of electricity storage technologies, and a $14m fund to assist the development and installation of wind forecasting systems. These are designed to reduce barriers to the increasing penetration of intermittent renewable electricity generation technologies.

Major state-level schemes

- The New South Wales Greenhouse Gas Reduction Scheme, a ‘baseline and credit’ emissions trading scheme which commenced in 2003, and sets a benchmark target of state-level per capita CO_2 emissions which is equivalent to 5% below the Kyoto Protocol 1990 baseline. The scheme will run until 2012.
- The Queensland 13% Gas Scheme which imposes an obligation on suppliers to source a minimum of 13% of electricity from gas-fired generation. The scheme operates in a broadly similar manner to the MRET, commenced in 2005 and will run until 2020.

High level policy goals

Taken together, these measures represent an attempt to address the problem of helping technologies to address systems failures associated with moving along the innovation chain and bridging the 'valley of death'. However, some have suggested that further measures and a clearer framework are needed. For example, the Australian Business and Climate Group (Australian Business and Climate Group 2007) suggests that the rate of low carbon technology development and adoption must be 'faster than the usual commercial timeframes' if substantive CO_2 reductions are to be achieved in the next two to three decades. The Group has proposed the adoption of a National Low Emissions Technology Strategy to provide a clear long-term framework within which objectives and priorities for low emission technology demonstrations and first-of-a-kind commercial plants can be set. This would seek to address funding gaps in the innovation chain, and the problems facing first movers and innovators in capturing value from their investments.

The next section provides a review of the main innovation and investment related issues that might need to be considered in designing policies to promote low carbon innovation in the Australian context. It seeks to point up areas where further analysis is likely to be valuable, rather than to provide a definitive analysis in itself.

5.4 Innovation systems, investment decisions and the Australian context

The innovation systems approach suggests that supporting low carbon technologies such as renewables and CCS to commercialisation is likely to need an appropriate mix of policy options. The policy mix needs to be designed with attention to technical maturity, market potential and investment risk. The mix might include a combination of public funding for R&D, grants for demonstrations, regulation to create fixed price support (feed in tariffs) and/or tradable obligations such as the MRET and RO, and carbon pricing through taxation or carbon trading. Ideally (from an innovation systems perspective) such policies form part of a broader set of climate policy goals, including long run targets, which help to shape the expectations of investors and innovators (see Section 3). Analysis of which policies to pursue needs to reflect technology and market risk and technology maturity and Australian energy resources, energy system constraints and policy goals.

In what follows, four key areas are highlighted where further analysis could enhance Australian innovation policies in the low carbon arena.

Price volatility, electricity prices and lock-in to a coal based system – the case of CCS

With such low coal and power prices, low carbon options face a more challenging incumbent 'benchmark' than they might in countries with higher power prices. In a very real sense, Australia is 'locked-in' to coal fired generation. It could also be argued that the dominance of coal, in terms of the indigenous resource availability, its use in power generation and its value as an export commodity are all strong drivers for the development of carbon capture and storage (CCS) technologies in Australia as part of the Australian response to climate change. This is reflected in the 2004 Energy White Paper (Energy Task Force 2004), and for this reason this sub-section focuses on discussion of price risk and policy on CCS.

As discussed in Section 4 the degree of volatility of wholesale electricity prices has significant implications for the investment decisions made by generators, and in Britain volatile electricity prices militate against investment in capital-intensive low carbon technologies. As illustrated in Figure 5.3 prices in Australia vary by region, and as in the UK volatility has increased since privatisation. The electricity price rises induced by gas price increases in Britain and other countries with a large share of gas fired generation will obviously be more muted in Australia, varying within Australian regions. Nevertheless, to the extent that price volatility remains a feature of Australia's power pools (something that the authors are unable to comment on) it will make investment in capital intensive technologies more risky. This is particularly true for technologies that will be most economic to operate on 'baseload' (see above), such as CCS, or which fluctuate independently of demand, such as wind or wave power. For reasons discussed below, the daytime price spikes seen in some states may be beneficial to PV, so PV is treated separately as a 'special case' here.

In some respects the investment conditions described for nuclear power in Britain are mirrored for carbon capture and storage in Australia. In both instances financing large capital costs is most likely to be feasible if plant is operated at maximum output, which suggests that the plant is unlikely to be a 'price maker'. Moreover, with high capital costs to finance a period of low wholesale prices would be a significant risk to investors. However, because variable costs (associated with fuel and operational costs associated with capture plant) are a larger fraction of total costs for CCS than for nuclear or renewables it is possible that some price risks will pass through to consumers in the same way as they do for gas-fired plant in Britain. Policy support for CCS requires careful analysis of the investment risks associated with the development of new infrastructure, exposure to price risk and a range of other factors.

Options to provide financial support for CCS include direct regulation (with or without a tradable scheme such as the MRET/RO), a feed-in tariff type arrangement, capital subsidy and public ownership of some of the asset base. As far as the authors have been able to ascertain there has been no detailed analysis anywhere in the world of the most appropriate mechanisms to support CCS beyond the demonstration stage[19]. Policies aimed at larger scale commercialisation deserve further analysis. If the Australian Government wishes to take a lead in developing CCS the specific risks imposed by Australian electricity markets need to be factored into the analysis. This would enable policymakers to decide whether or not it is appropriate to remove price risk from investors (through a feed in tariff or other fixed price scheme).

Renewable energy policy choices

This sub-section considers Australia's main near market support scheme for low carbon options, the MRET. The MRET is very modest in comparison with existing renewables capacities and future goals in Europe, the US and Japan. For example the UK Renewables Obligation will rise to around 80 TWh/yr in 2020, nine times the level set for the MRET. Installed capacity of wind power in the US, Germany and Spain is 12 GW, 21 GW, and 12 GW respectively, compared to 800 MW in Australia (Windpower Monthly 2007). MRET is also a little more than two year's worth of forecast electricity demand increases (Energy Supply Association of Australia

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[19] Demonstration schemes are being mooted by the EU, US, UK and Chinese governments amongst others.

Limited 2007). The rationale for deciding not to increase the MRET target beyond 2010 was that the estimated additional costs to the economy 'could not be justified' (Energy Task Force 2004). It may now be appropriate to review this conclusion in the light of the findings of the Stern Review and others on the increasing likely economic and social costs of the impacts of climate change, if sufficient action is not taken. Others have argued that the MRET should be increased substantially, along with other measures to promote renewables (Saddler et al. 2004).

It is important to note that the low electricity price in Australia relative to many other countries combined with high per capita electricity consumption increases the marginal impact of renewables support measures. All other factors being equal the impact on bills will be larger, per MWh of renewable output, than it would be in countries with higher prices and lower per capita consumption. Against this, however, it is also important to note that renewable generation costs are driven in very large part by resources. Wind energy is a particularly good example, since output is a function of the cube of the wind speed. Australia has excellent wind, solar, wave, tidal and other resources. The cost burden imposed by renewables on consumers is relatively straightforward to assess (see e.g. DTI 2003).

Should a decision to expand or revise the MRET be taken then it would also be important to assess the nature and diversity of renewable technologies that the government wishes to support. The problems created by the 'one size fits all' nature and price risks of the Renewables Obligation are well documented (DTI 2006b; Gross et al 2007; Mitchell & Connor 2004). As a result the UK government intends to 'band' the RO. Commentators have suggested that the resulting complexity is considerable, whilst noting that any substantive distinction between the RO and fixed price schemes is rather limited (RO price becomes a product of prevailing costs of technology in each band). The predominance of fixed price feed in tariffs in countries that have expanded their renewables industries rapidly is also well understood (Stenzel et al. 2003), as are the reasons that investors prefer fixed rate tariffs to certificate trading schemes (European Commission 2005; Gross et al 2007). It appears sensible therefore for the Australian policymakers to consider carefully the merits of fixed price schemes, differentiated by technology. Irrespective of which support route is chosen technology differentiation is particularly important in Australia given that a wide range of technologies offer considerable potential.

The special case of PV?

Given the high degree of correlation between PV output and summer electricity daytime price 'spikes' the potential for PV to make a cost effective contribution to both so called 'peak shaving' and to carbon targets is significant. The economics of PV are highly location specific. In some instances it is already cost competitive in remote regions with high power demand met by diesel generators, or for building integrated use where insolation is good and end user tariffs are particularly high [20,21].

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[20] Report by Jefferies Investment Bank Inc, and quotes by General Electric cited in Reuters report http://www.reuters.com/article/environmentNews/idUSL1878986220071019?pageNumber=2&virtualBrandChannel=0&sp=true

[21] For example under some assumptions PV levelised costs may be cheaper than the domestic tariff in Italy http://epp.eurostat.ec.europa.eu/pls/portal/docs/PAGE/PGP_PRD_CAT_PREREL/PGE_CAT_PREREL_YEAR_2006/PGE_CAT_PREREL_YEAR_2006_MONTH_07/8-14072006-EN-AP1.PDF

Policies to promote PV and other forms of solar power therefore deserve important attention, as is recognised by the Solar Cities Trial and other projects. From an investment perspective it is important to note the nature of investors in building integrated PV differ markedly from the electricity industry ‘norm’, being comprised of building developers, householders and businesses of a range of sizes. Access to capital, risk aversion, information barriers and a range of other factors need to be assessed and addressed if policies to promote PV are to be successful. However ‘central station’ PV arrays, as might be deployed in desert locations, and concentrating solar thermal schemes, possibly co-fired by gas, are clearly much more similar to conventional power station investments. Policies for small scale investors will be markedly different from those that suit utilities and power companies. In both cases, further analysis is needed to understand in more detail the barriers that need to be addressed and the investment needs of potential developers.

It is also important to take stock of progress under different types of support mechanism for decentralised options such as building integrated PV in other parts of the world. The British government has noted that the complexities and transaction costs faced by prospective investors in PV who wish to secure Renewables Obligation Certificates (ROCs) represents an important barrier to adoption of PV (DTI & Ofgem 2007). Successful PV development schemes in California, Germany and Japan have all used a combination of capital grants and high fixed price payments for PV output. There is no example anywhere in the world of the successful application of a certificate trading (RO/MRET) approach to the development of PV.

A balance of support from RD&D through to commercialisation

Australian policies have a considerable focus upon schemes that seek to promote the development of technologies through demonstration and piloting. With the exception of the MRET, there is little in the way of ‘near market’ support for emerging technologies. Moreover with the exception of the New South Wales Greenhouse Gas trading scheme there is no mechanism to price carbon emissions. The relatively modest target set by the MRET suggests that there is likely to be a gap in the innovation system for renewables and other low carbon options – successfully demonstrated technologies have little prospect of further development in the absence of policies to allow their continued growth. This could be addressed through policies to promote solar power or CCS (see above).

Australia also lacks a ‘top level’ policy to internalise the costs of CO2 emissions, or any form of high level targets. Section 4.5 explains the importance of expectations to investors in low carbon power. High level policy commitments cannot in themselves deliver the development of lower carbon options, but they are important in shaping expectations.

Infrastructure and location

The final, perhaps rather obvious final point of note about Australia relates to the location of renewables resource, CCS repositories and demand centres. Investment in infrastructure faces particular difficulties, such as first mover disincentives. For example, unless there is a coincidence of a demand centre and suitable carbon storage geology, then CCS implies either CO_2 pipeline and/or electricity transmission infrastructure investment, which in turn must be rewarded in the electricity market (if the market is expected to build the new infrastructure). Similar issues apply to some renewables. Investment in infrastructure to access ‘remote’ renewables has proven to be of great importance to the development of low carbon technologies even in the British context of very much shorter distances. The British government and electricity regulator have permitted the tightly regulated transmission system operator to expand investment by around £5billion in the period to 2015, largely in order to accommodate new renewables developments in Scotland where transmission is constrained (British demand is highest in the south whilst much renewable resources are located in the north). It has also made provision for investment in offshore electricity infrastructure in order to unlock Britain's offshore wind resource (DTI 2007b). Since 'remote' in the British context is only of the order of a few hundred miles the challenge in Australia is clearly larger and has the potential to be significant to the development of low carbon energy. Infrastructure needs, and associated investment issues, are therefore likely to be particularly important to Australian innovation systems analysis.

5.5 Summary

Policies are already in place to support an innovation in low carbon energy in Australia, however additional research is needed into how these can be enhanced and improved. The innovation systems approach and attention to investment risk suggests that additional work might focus on the following key issues:

- ***Options for providing a long term framework to promote a transition to low carbon energy*:** Goals and targets are important to investor expectations, but it is also important that policies to promote innovation directly are accompanied by policies to price carbon emissions, whether through trading schemes (as already in place in NSW) or taxation.
- ***Options to provide financial support for demonstration and commercial scale roll out of carbon capture and storage.*** Capital grants might be appropriate at the demonstration stage, but mechanisms for commercial scale development are yet to be analysed in detail anywhere in the world. If the Australian government wishes to take a lead in the development of CCS then the risks imposed by electricity markets need to be factored into an investment focused analysis that considers a wide range of policy options including grants, RO/MRET style obligations and feed in tariffs.
- ***Policies to encourage the development of large scale renewables need to be reviewed.*** Should a decision to expand or revise the MRET be taken it is also important for the government to assess the nature and diversity of technologies it wishes to support, and the most effective mechanism for promoting such diversity. The predominance of feed in tariffs in countries that have expanded their renewables industries, and the problems for investors created by tradable certificate schemes such as the RO/MRET, are well documented.
- ***Policies to promote PV deserve particular attention in Australia for climatic reasons and because of the close match between PV output and demand profiles.*** The importance of solar power is already reflected in Australian policies. Experience from around the world indicates that small scale investors face particular barriers, and policies need to be targeted towards these. Successful support schemes for small scale PV use a mix of capital subsidies and fixed price payments for output. Transaction costs and complexities represent a considerable barrier to householders or small businesses accessing markets for renewable certificates.

- ***Policies to facilitate infrastructural investment deserve particular attention in Australia because of the potentially large distances involved in terms of electricity transmission and CO2 transport.***

6 Concluding Remarks

This report has articulated a framework for analysing innovation systems. Analysts of innovation have highlighted the extent to which a range of economic, institutional and technical factors can create ‘lock-in’, such that the global economy is locked into a carbon intensive energy system. Overcoming this lock-in requires a concerted effort on the part of policymakers to both promote the development of new lower carbon options and to provide the opportunities for them to begin to compete with incumbent technologies in the market place.

The innovation system approach facilitates an improved understanding of both the systemic interactions that allow innovation systems work successfully and the types of policies that are best suited to support innovation when innovation systems fail. This includes a range of policies that can target support to different stages of technology development. Innovation systems analysis also highlights the importance of a long term and consistent strategic policy framework to promote a transition to a low carbon energy system. This framework can shape expectations and build investor confidence; it should include long term goals and policy commitments, but also needs to include mechanisms which place a market price on carbon.

The specific policies to promote innovation include support for R&D, grants and incentives for demonstration, the creation of ‘niche’ and ‘lead’ markets through public procurement and price support mechanisms such as feed in tariffs, as well as direct regulation, to support the longer-term development of markets for new low carbon technologies. In all cases, the objective is to support technologies such that they can compete directly with fossil fuel based options, assuming a market price for carbon.

This list of policy types is of course relatively simple, but the devil is in the detail, and the specifics of policy design are critical to policy success. Choosing between, for example, fixed price support schemes like the German feed in tariff and the UK/Australian (MRET/RO) approach requires careful attention to issues of price risk, access to cost information, technology risk, nature of investor, and a range of other factors. There are few instances where ‘one size fits all’, since promoting innovation requires a basket of carefully crafted policies. What works for near market options or large scale technologies will not necessarily suit the small investor or technologies perceived to be immature and risky. Innovation policy development, like innovation systems thinking, is an emerging endeavour that requires a willingness to learn from experience, adopting and adapting policies as innovation proceeds. However, the reward for a well designed mix of innovation policies is very large indeed. It offers the potential both to help deliver deep cuts in carbon emissions with minimal negative economic impact *and* to encourage valuable new industries to grow in the emerging low carbon sector.

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