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The Role of Technological Innovation in Meeting California's Greenhouse Gas Emission Targets

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Chapter 3:

The Role of Technological Innovation in Meeting California's Greenhouse Gas Emission Targets

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OUTLINE

1 Introduction

Rising concentrations of greenhouse gases (GHGs) in the atmosphere have already caused perceptible changes in climate and will lead to further climate change in the future (Intergovernmental Panel on Climate Change 2001). The impact of climate change in California may be particularly significant in some areas: water resources, agriculture, and sensitive coastal and forest ecosystems (Shaw 2002; Roos 2003; Hayhoe, Cayan et al. 2004). In turn, these impacts could have serious repercussions for the economy and public health of the State, and for California's agricultural and recreation industries.

On June 1, 2005, recognizing and responding to dangers posed to California by climate change, Governor Schwarzenegger signed Executive Order # S-3-05 (Schwarzenegger 2005). The Executive Order established the following GHG emission reduction targets for California:

- by 2010, reduce GHG emissions to 2000 levels;
- by 2020, reduce GHG emissions to 1990 levels; and,
- by 2050, reduce GHG emissions to 80 percent below 1990 levels.

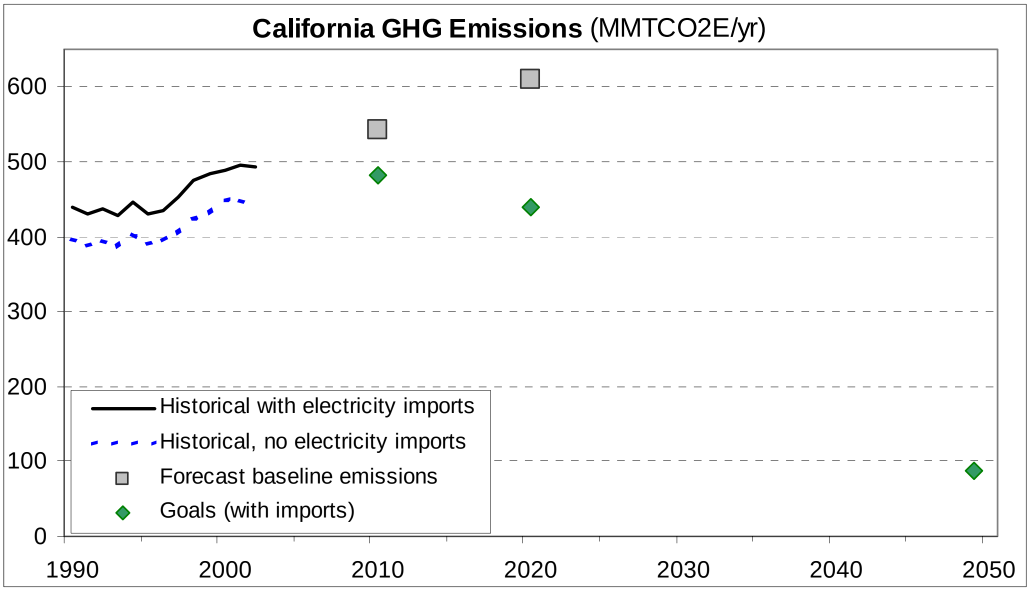
The Governor's 2010 and 2020 targets represent a modified version of the Kyoto Protocol target – reducing GHG emissions in California to the level of 1990, but by 2020 rather than 2012. The 2050 target is something far more novel and significant. This is, in fact, the type of reduction in GHG emissions that developed countries around the world will need to achieve about that time if the atmospheric concentration of carbon dioxide is to be stabilized at double the pre-industrial level, rather than continuing to rise to levels that could bring very dangerous consequences (Wigley, Richels et al. 1996; O'Neill and Oppenheimer 2002). Although California is the first state to confront the prospect of a substantial de-carbonization of its economy by mid-century, this will become the central focus of post-Kyoto climate policy for all developed countries.

Because of their scope, the Governor's targets require a portfolio of different strategies. The strategy to meet the 2010 and 2020 targets is to draw on existing technologies that are presently in use or on the verge of deployment, and to fashion a set of incentives that shift the normal pattern of economic activity and growth towards less carbon-intensive or less energy-intensive technologies using a combination of an intensification of the environmental and energy conservation programs already in place in California plus the introduction of some new ones targeted specifically at GHG emissions.

To meet the 2050 target, a different approach is required. This calls for a profound refashioning of the economy, comparable to the shift that was triggered by the energy crisis of the early 1970s, or the shift that is still occurring following the introduction of micro-computers in the late 1980s and the Internet in the 1990s. Computers and the Internet can help with the decarbonization of the economy, but they are not sufficient by themselves. It will also require new technologies, new institutions, and new industries. At this point, we do not know what those technologies will be – or rather, we know the potential set of these technologies, but we do not yet know which will turn out to be winners, and which losers or has-beens. The development and deployment of new technologies takes time, and none of this will happen overnight. But that does not mean California should do nothing right now. To the contrary, because of the long lead-time California needs to have in place now a pro-active and effective program for the promotion of technological innovation targeted at the decarbonization of the California economy. Moreover, because of the long life of capital in the energy sector and other GHG-intensive industries, as well as of infrastructure associated with land use and transportation, California needs to take action now to align its other economic, transportation, and land-use policies to facilitate the eventual decarbonization of the economy and pave the way for the economic, social and technological innovations that will be required to meet the 2050 targets.

Figure 3-1 illustrates recent trends in California's GHG emissions as well as the Governor's 2010, 2020, and 2050 goals.

Figure 3-1: Recent GHG emissions[1] in California and Governor Schwarzenegger's goals.



Source: Bemis and Allen, 2005.

Anthropogenic activities generating four different gases – carbon dioxide (CO_2) from fossil fuel combustion, nitrous oxide primarily from agriculture and transportation, methane primarily from agriculture and landfills, and "high global warming potential" gases used in industry – account for almost all GHG emissions in the state. As shown in Figure 3-2, technologies in transportation, industry, electricity generation, agriculture, commercial and residential buildings, and waste disposal are all candidates for the significant changes necessary to meet the 2050 targets.

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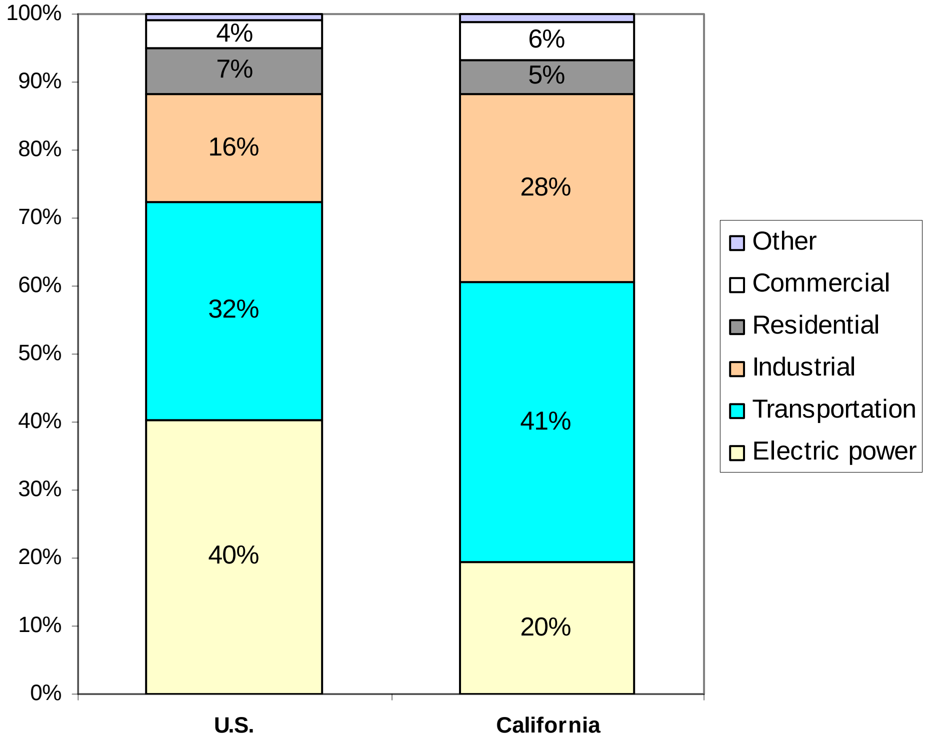
[1] Numbers are totals net of sinks (e.g., forest growth, rangeland improvements, landfill lumber disposal, and yard trimming landfill disposal). In 2002, for example, Bemis and Allan (2005) estimate that these sinks reduce emissions by 22.3 MMT CO2 equivalents.

Figure 3-2: GHG emissions by end-use sector, including electricity generation, 2002[2]

Source: U.S. data from U.S. Environmental Protection Agency (2005); California data from Bemis and Allen (2005



CO_2 is the most prominent of these gases; even without imported electricity in the calculation, 83% of California GHG emissions are carbon dioxide (CO_2) emissions from fossil fuel combustion, a percentage that has held quite steady between 1990 and 2002 (Bemis 2005 note 31). On a per capita basis, however, California has very low emissions of CO_2 from fossil fuel combustion: California has the fourth lowest emissions per capita of the 50 states and Washington, D.C. Figure 3-2 shows how the sources of GHG emissions in 2002 differed between California and the nation as a whole; emissions from electric power are considerably smaller and emissions from transportation are considerably higher than the rest of the nation. A large part of the story behind that unique CO_2 profile is due to technology choices California has made in the electricity sector in the past.

There are several basic strategies that can be used to reduce GHG emissions from fossil fuel combustion; we elaborate them here in the context of electricity in California. One strategy is to keep the combustion process the same while controlling emissions; this can be done either through pre-combustion interventions such as fuel switching (for example, from oil to natural gas, as California has done), or through post-combustion interventions such as carbon capture and sequestration, a new technology in development in a number of areas around the world. A second strategy is to keep the combustion process the same but reduce demand for the power that results from combustion; this can be done either through encouraging greater efficiency in end-

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[2] Bemis and Allen (2005) provide sector breakdown for transportation, commercial and industrial sectors. Some classification required of emissions' sources to calculate breakdown between residential and commercial sectors.

use devices (California is a world leader in energy efficiency) or by meeting some of this demand for power in end-use devices with alternatives to fossil-fuel fired generation (California had an important early experiment with solar water heating that is relevant to this strategy). A third strategy is to generate power with alternatives to fossil fuels, such as water, wind, and sun; California has a considerable amount of hydropower, basically started the modern wind industry, and has played an important role in U.S. solar thermal electricity and photovoltaic research.

California, therefore, has a rich history of experience with reducing GHG emissions from fossil fuel combustion in the electricity sector that can be drawn on by other states and sectors interested in reducing their emissions from fossil fuel combustion. At the same time, a lot of the "low-hanging fruit" in GHG emissions reduction from this sector has already been accomplished, which leaves the electricity sector with a greater challenge to meet the 2050 targets. Past state experience with the dynamics of environmental innovation in this sector, however, could prove a useful guide to the most effective future innovation strategies for meeting these targets.

What is environmental innovation? It is innovation that occurs in environmental technologies, which are products and processes that either control pollutant emissions or alter the production process, thereby preventing emissions altogether. These technologies are distinguished by their vital role in maintaining the "public good" of a clean environment. Unfortunately, the common finding in the economics of innovation literature that industry tends to under-invest in research, development, and demonstration (RD&D) generally, compared to the societal returns of that RD&D (see Griliches (1992) and Jones and Williams (1998), for example), is enhanced in the case of environmental innovation.[3] This is because there are weak (if any) incentives for private investments to provide public goods like a clean environment. Thus, environmental technologies are developed not just in response to competitive forces; they are also advanced, to a considerable extent, by specific government actions. For example, the market that pollution control technologies satisfy is fully defined by government, as the technologies produce no economically valuable good in and of themselves. The market that alternative energy technologies satisfy, on the other hand, is shaped by a more equal combination of the privately valued and publicly valued characteristics of the energy they provide; such privately valued characteristics include cost, availability, and other performance attributes of energy, while their publicly valued characteristic is their impact on the environment.

A number of actors are sources of environmental innovation. Most of the innovation in technology strategies for GHG emissions reduction clusters around the firms that manufacture environmental technologies. These firms are sources of innovation in and of themselves, but they are also embedded in strategic relationships with suppliers, customers, competitors, and manufacturers of substitute technologies, each of which can also be a source of innovation. Other sources of innovation in the "industrial-environmental innovation complex, depending on the technology, include the firms that emit pollutants, universities, trade associations, and the Electric Power Research Institute (EPRI, the electric power industry's rather unique R&D consortium). In the midst of this activity is government itself, which can conduct research, fund

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[3] The economics of innovation literature dates back to Schumpeter (1942) and has provided much of the academic thought on the definitions and metrics of the innovation process, as well as the interplay between innovation and such things as market structure and firm size.

external research (often in partnership), and transfer knowledge about new developments both to and between other innovators through a variety of means including industry-specific conferences, publications, and collaborations. Finally, innovators outside this complex are also important sources for new innovations.

Besides the "technology-push" (shifting the supply curve) activities just described, government has implemented different policy instruments in the past that have served as "demand-pull" (shifting the demand curve) events.[4] On the regulatory side, the diffusion of environmental technologies can be induced through such government actions as: (1) setting a "bubble" target for air quality in a region that cannot be exceeded by new or existing sources of emissions; (2) setting an emissions "cap" that emitting sources have to live under unless they purchase additional emissions "credits" from entities with credits to sell because they have been environmental over-achievers under this cap (in the past, caps have been modest and phased in gradually); and (3) setting "performance-based" standards for the emissions from specific categories of sources, as measured over a particular time-frame. Performance based standards provide the least complex demand signals to environmental technology suppliers of these three options, although that signal can be technologically neutral for substitution technologies.[5] Cap-and-trade schemes are generally credited with such technological neutrality as well, although in practice, caps and performance targets are typically set with some consideration of the available technologies.[6]

On the financial side, the diffusion of environmental technologies can be induced through such "demand-pull" government instruments as: (1) investment subsidies like tax credits (for example, to build wind turbines) and product rebates (for example, for the residential installation of energy efficient technologies); (2) production subsidies, such as production tax credits (for example, for the production of power from wind turbines) and guaranteed rates for the price of power from renewable sources; and (3) renewable portfolio standards (RPS) that require that a specified amount of renewable energy is included in the portfolio of electricity resources serving a geographic area. RPSs change the competitive playing field for renewable sources of power from a straight cost-based competition against fossil fuels to a cost- and performance-based competition against other renewables in a market set aside for these sources.

Figure 3-3 sketches the primary innovative activity that "technology-push" and "demand-pull" government actions, broadly defined, are designed to affect within the innovation process. These innovative activities – invention, adoption, diffusion, and learning by doing – overlap each other and allow feedback to occur between them. Some definitions are in order here. As stated in Clarke and Riba (1998), "an invention is an idea, sketch, or model for a new device, process or system." "Adoption" is the first commercial implementation of a new invention. "Diffusion"

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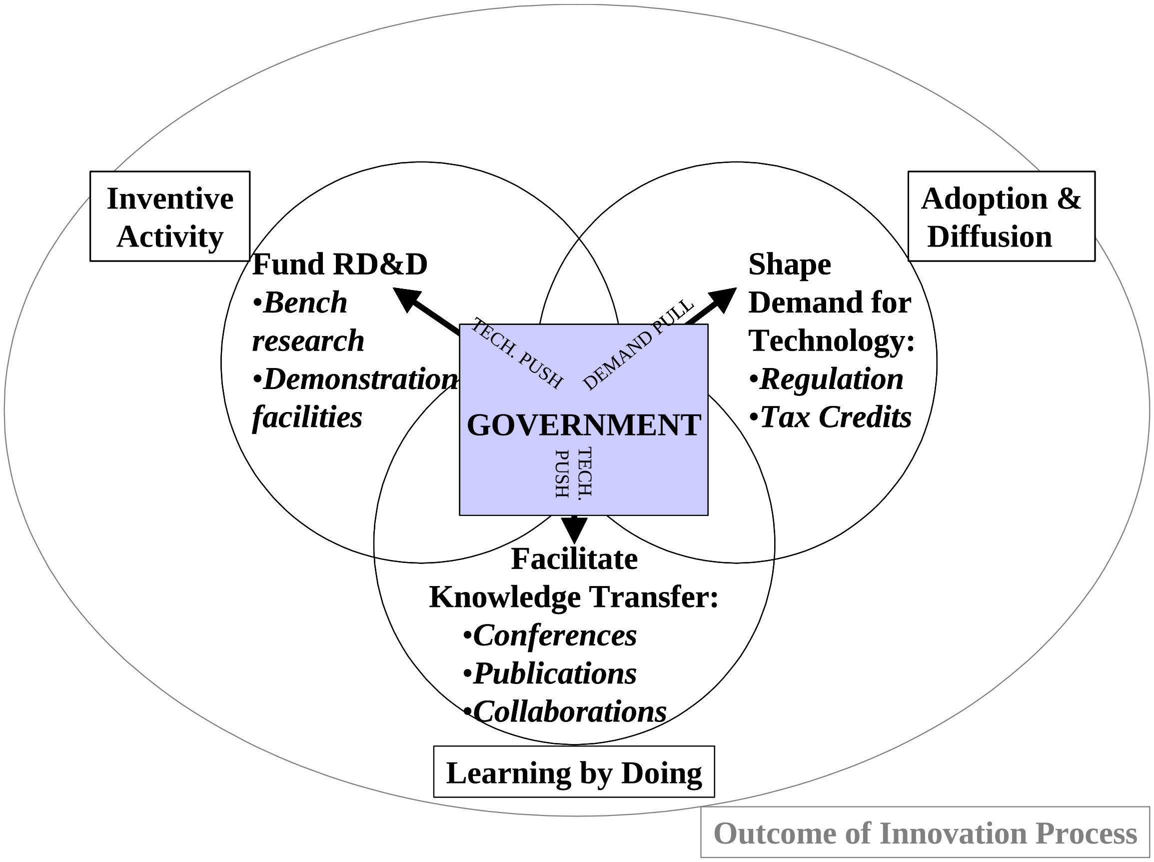
[4] This terminology is an application of concepts from the economics of innovation literature.

[5] As in the case of early standards for sulfur dioxide (SO_2) set on coal-fired boilers on the basis of the maximum allowable emission rate of SO_2 in terms of pounds of emissions per MBtu heat input, as opposed to later SO_2 standards based on a percentage reduction, tagged to the performance of specific technologies, of potential emissions from high and low sulfur coals.

[6] In the SO_2 case described in footnote 5, for example, the standards required a "technology basis" in which EPA had to stipulate which control technologies were "adequately demonstrated" for use by utilities.

refers to the widespread use of a commercial innovation, and is often studied as a communication process between current and potential users of a technology (Rogers 1995). Finally, "learning by doing" refers to the post-adoption innovative activity that results from knowledge gained from difficulties or opportunities exposed through operating experience (for a discussion, see Cohen & Levin 1989). Note that the innovative activities in the figure are enclosed in a circle that demarks the full innovative process; while the outcomes of innovation are manifest outside this circle.

Figure 3-3. The role of government actions in the environmental innovation process.



Source: Taylor et al. 2005b

This complexity – in terms of the types of activities required for innovation, the government "technology-push" and "demand-pull" instruments that influence these activities, and the numerous sources of these activities – is the main reason why it is difficult to answer the question, "What are the best policies to pursue to induce the innovation necessary to achieve the state's greenhouse gas emissions targets?" This chapter of the report seeks to contribute empirical insights from several climate-relevant technology cases to help California consider the implications of policy design and implementation for innovation in GHG emissions reduction technologies. The research approach used in investigating these cases is a systematic integration of analyses of U.S. patents, public research laboratory activity, technology conference proceedings, learning and experience curves that document cost and performance changes with cumulative operating experience, and interviews with experts. Taken together, these methods yield a broad understanding of the environmental innovation process, with insights into the nature and complexity of the government's role in environmental innovation. In this chapter, observations of the interaction between government actions and innovation are collected across these cases for the first time, and recommendations are then made for California policies to reduce GHG emissions.

The second section of this chapter reviews the environmental innovation literature and the treatment of technological change in the climate modeling literature. The third section introduces seven cases of innovation in climate-relevant technologies that were driven, to a significant extent, by government actions, collates observations seen in two or more cases, and discusses cost and performance trends across cases. The final section of the chapter considers what the "lessons-learned" from these cases might imply for California climate policy going forwards.

2 The Literature on Environmental Innovation and Technological Change in Climate Modeling

2.1 Environmental Innovation Literature

As reviewed in Taylor et al. (2005b), there is a long-standing debate about how policy instruments can best be used to induce innovation in environmental technologies (early papers on this topic include Rosenberg 1969; Kneese and Schultze 1975; Magat 1978; and Orr 1976).

As discussed above, one of the main issues in the economics of innovation literature relevant to this discussion is the relative importance in driving technological innovation of "technology-push" (shifting the supply curve) versus "demand-pull" (shifting the demand curve). The literature on environmental policy instruments and innovation, however, has tended to focus less on broad types of government actions related to this issue – government "technology-push" through public funding of RD&D versus "demand-pull" through the market that policy can create for an environmental technology, for example – than on the effectiveness in inducing innovation of specific attributes of regulatory "demand-pull" instruments (for a critical review of this "environmental technology" literature, see Kemp 1997).

Although such regulatory characteristics include efficiency, flexibility, stringency, differentiation, phasing, enforcement, uncertainty, and the potential market for environmental equipment suppliers to meet, the largest body of work on this topic has dealt with regulatory efficiency, or whether the policy instrument mimics the "free market" in its allocation of private sector resources. Other well-known work on this topic has focused on regulatory stringency and uncertainty. In this section, we review some of the major arguments here, while acknowledging that there is much still to be explored in this literature, especially in the areas of government "technology-push" and some of the less-studied attributes of regulatory "demand-pull."

2.1.1 Regulatory Efficiency

The dominant viewpoint on regulation and innovation is arguably that of supporters of "economic incentives" like cap-and-trade programs and emissions taxes, who claim that such instruments induce innovation to a greater extent, and more continuously, than "command-and-control" regulation (see economic work on "dynamic efficiency," including Jaffe & Stavins 1995, Baumol & Oates 1988; Downing & White 1986; Marin 1978; Milliman & Prince 1989; Orr 1976; Smith 1972; Wenders 1975; and Zerbe 1970). Supporters of economic incentives link the allocative efficiency of this type of instrument to the flexibility the instrument allows firms in making compliance technology choices; the assumption is that command-and-control regulation is less flexible and therefore provides less incentive for innovation.

Although a number of researchers dissent from this viewpoint, Driesen (2003) provides one of the most comprehensive counterarguments to date. First, he questions the basis for the comparison itself, as the distinction between "command-and-control" regulation versus economic incentives is false. He argues that most traditional environmental regulation provides a flexible, negative economic incentive (a "stick") that induces regulated firms to innovate in a technology in order to meet a proscribed level of environmental performance at the lowest possible cost using "any adequate technology [a firm] choose[s]." Second, he argues that programs like emissions trading that aim for regulatory efficiency probably "weaken net incentives for innovation" (Driesen 2003: 64). This is because although they provide over-compliance inducement incentives for innovation by pollution sources with low marginal control costs (selling their excess credits becomes a "carrot" for innovation), they provide an equal measure of under-compliance inducement incentives for innovation by pollution sources with high marginal control costs. Third, Driesen shows that neither traditional regulation (such as programs that prohibit additional emissions despite economic growth) nor market-based mechanisms like emissions trading (which limits the number of tradable permits despite economic growth) provides a more continuous incentive for innovation.

2.1.2 Regulatory Stringency, Anticipation, and Uncertainty

Beyond the regulatory efficiency debate, the main body of literature on regulation and innovation focuses on the existence and anticipation of regulation, as well as the stringency and certainty of that regulation, as important drivers of innovation. Several studies, including an innovation survey of U.K. firms by Green et al. (1994), cross-national industry interviews by Wallace (1995), a diffusion study of the Ontario organic chemical industry by Dupuy (1997), and, most famously, a review of ten cases of regulation between 1970-85 by Ashford et al. (1985), point to the importance of existing, and even anticipated, government regulation in driving the development and deployment of environmental technologies. In addition to these empirical studies, the "Porter Hypothesis" very prominently advanced the theoretical argument that tough environmental standards that stress pollution prevention, do not constrain technology choice, and are sensitive to costs, can spur innovation and thereby enhance industrial competitive advantage (Porter 1991); a body of work is growing around this hypothesis.

On the issue of stringency, Ashford et al. find that "a relatively high degree of [regulatory] stringency appears to be a necessary condition" for inducing higher degrees of innovative activities (Ashford 1985, note 36 at 429), and that is the dominant view among case studies.

Two of the most prominent empirical economic studies on this relationship have contradictory results, however: Jaffe and Palmer (1997) find no statistical correlation between stringency (as represented by pollution abatement expenditures) and innovation (as indicated by patenting activity), while Lanjouw and Mody (1996) show the two variables paralleling each other with roughly a two-year lag. Both of these empirical studies can be critiqued based on features Kemp (1997) identifies as distinctive to innovation in environmental technology. Jaffe and Palmer (1997) conduct their analysis as if regulated firms perform all of the inventive activity measured by patents, although the important innovative role of other organizations (especially environmental technology suppliers) has been well established. Meanwhile, Lanjouw and Mody (1996) assume, for measurement purposes, that "all environmentally responsive innovation in a field responds to events in a broadly similar fashion" (Lanjouw and Mody 1996: 557). Yet different technologies focused on the same environmental problem area often exhibit a variety of control efficiencies, and may well react differently to different standards (such as when standards are strengthened so that a pre-existing technology will no longer meet the new standard).

In addition to these problems, both studies rely on aggregate data sources that mask some of the complexities of environmental technological innovation. Studies that attempt to capture all environmental technology patents can generally be critiqued as overly ambitious, in light of the diversity of environmental technologies and limitations of the patent classification system. Lanjouw and Mody (1996), for example, attempts to cover nine environmental fields in their patent dataset: industrial and vehicular air pollution, water pollution, hazardous and solid waste disposal, incineration and recycling of waste, oil spill clean-up, and alternative energy. Even though the authors say they are trying to err on the side of capturing too many patents rather than too few, the patent classifications they include for industrial air pollution alone are tremendously incomplete, missing almost 94% of the SO_2 control technology patents identified using the abstract-based method described in Taylor et al. (2005b). As this technology is one of the world's most famous and well-understood examples of air pollution control technology, this puts the results of this study in great doubt.

Finally, uncertainty has not been as well-studied as regulatory stringency in driving innovation, and results are currently vague. According to Wallace (1995), unpredictable and inconsistent policies thwart innovation by creating uncertainty for prospective innovators. Ashford et al. (1985) take a more balanced stance, stating that too much uncertainty may stop innovation, but too little "will stimulate only minimum compliance technology" (Ashford 1985: 426). Both studies could benefit from a more precise understanding of the various activities that comprise the innovation process.

2.2 Technological Change in the Climate Modeling Literature

As reviewed in Yeh et al. (2005b), assumptions concerning the nature and rates of technological change are arguably among the most critical for assessments of long-term energy and environmental issues such as global climate change. Large-scale integrated assessment (IA) models used for energy and environmental policy analysis traditionally have employed exogenously specified schedules or rates of improvement in technology performance and/or cost (Kypreos, 1992, Manne and Richels, 1992, Nordhaus, 1994, Prinn 1999). The principal drawback of this method is that technological change is assumed to be autonomous, free, and independent of other policy or economic variables. It has been shown, however, that improvements in technology are neither autonomous nor free, but dependent on factors like investments in research and development (Cohen 1996, Watanabe 2003), capital deepening (Cohen, 1995, Klepper, 2000), economy-of-scale effects (Sinclair, 2000), and the nature and stringency of government regulations (Taylor et al., 2003, Rubin et al., 2004b). In recent years, as computational barriers have fallen, endogenous models of technical change have gained increased acceptance and use in large-scale IA models, typically in the form of an "experience curve" (also called learning curves).

2.2.1 Experience Curves

Technology experience curves relate changes in specific investment costs to the cumulative installed capacity of the technology (a surrogate for the combined influence of factors such as those noted above). While experience curves remain an imperfect representation of technical change, they are nonetheless regarded as an important step toward more realistically representing the dependency of technical change on other factors in IA models. As reviewed in Nemet (2006), since studies in the 1990s began to use the experience curve to treat technology dynamically (Williams 1993; Grubler 1999), the experience curve has become a powerful and widely used model for projecting technological change. Recent work, however, has cautioned that uncertainties in key parameters may be significant (Wene, 2000, Yeh 2005b, Nemet 2006), making application of the experience curve to evaluate public policies inappropriate in some cases (Neij 2003).

The experience curve is derived from the learning curve, which originates from observations that workers in manufacturing plants become more efficient as they produce more units (Wright 1936, Alchian 1963, Rapping 1965). Drawing on the concept of learning in psychological theory, Arrow (1962) formalized a model explaining technical change as a function of learning derived from the accumulation of experiences in production. In its original conception, the learning curve referred to the change in the productivity of labor, which was enabled by the experience of cumulative production within a manufacturing plant. Others developed the experience curve to provide a more general formulation of the concept, including not just labor but all manufacturing costs (Conley 1970) and aggregating entire industries rather than single plants (Dutton 1984). Though different in scope, each of these concepts is based on Arrow's explanation that ''learning-by-doing'' provides opportunities for cost reductions and quality improvements.

The experience curve operationalizes the explanatory variable "experience" using a cumulative measure of production or use. Change in cost typically provides a measure of learning and technological improvement, and represents the dependent variable. Learning curve studies have experimented with a variety of functional forms to describe the relationship between cumulative capacity and cost (Yelle 1979). The log-linear function is most common, perhaps for its simplicity and generally high goodness-of-fit to observed data. The central parameter in the learning curve model is the exponent defining the slope of a power function, which appears as a linear function when plotted on a log–log scale. This parameter is known as the learning coefficient (b) and can be used to calculate the progress ratio (PR) and learning ratio (LR) as shown below where C is unit cost and q represents cumulative output:

$$C_t = C_0 (q_t/q_0)^{-b}$$

$$PR = 2^{-b}$$

$$LR = (1 - PR)$$

Several studies have criticized the learning curve model, especially in its more general form as the experience curve. Dutton and Thomas (1984) surveyed 108 learning curve studies and showed a wide variation in learning rates leading them to question the explanatory power of experience. Argote and Epple (1990) explored this variation further and proposed four alternative hypotheses for the observed technical improvements: economies of scale, knowledge spillovers, and two opposing factors, organizational forgetting and employee turnover.

Despite such critiques, the application of the learning curve model has persisted without major modifications as a basis for predicting technical change, informing public policy, and guiding firm strategy. In general, IA models that incorporate induced technological change tend to find accelerated rates of emissions abatement and lower costs of environmental compliance compared to models that ignore technological change (Grubler 1997, Messner, 1997, Grubler 1998, Grubb 2002b, van der Zwaan 2002). However, the sensitivity of policy-related variables to the assumed learning rates can be highly non-linear or even negative. Small changes in the assumed technology progress ratio can change investment patterns considerably, and thus the conditions for long-term competitiveness of new technologies (McDonald 2002, Barreto 2004).

Note that in addition to its use in IA models, the experience curve has also been an important tool for informing policy decisions related to energy technology. Nemet (2006) notes that the experience curve has provided a method for evaluating the cost-effectiveness of public policies to support new technologies (Duke 1999) and for weighing public technology investment against environmental damage costs (van der Zwaan 2004).

3 Technology Cases

Table 3-1 shows the technology cases explored in this chapter, according to the technology strategy they represent (as laid out in the introduction to this chapter). Note that although the technology strategy typology introduced above is specific to the electricity sector, here it is extrapolated into the transportation sector as well.

Table 3-1. Typology of some of the technology strategies useful to controlling CO_2 emissions (83% of California's GHG emissions in 2002), with cases discussed in this chapter.

Sector	**Technology Strategy**		**Cases Discussed in this Chapter**
Fossil Fuel Combustion – Traditional Electricity Generation	Control Emissions	Pre-Combustion	
		Post-Combustion	SO_2 (FGD) and NO_x (SCR) Control (analogous to carbon capture & sequestration)
	Reduce Demand for Generation	End-Use Efficiency	
		End-Use Independence	Solar Water Heating
Alternative Electricity Generation	Centralized		Wind Power, Solar Thermal Electric Power
	Distributed		Photovoltaic Cells
Fossil Fuel Combustion – Traditional Engine Transportation	Control Emissions	Pre-Combustion	
		Post-Combustion	Automotive Emission Controls for Criteria Pollutants (analogous to CO_2 control technologies?)
	Reduce Demand for Fuel	Fuel Efficiency	
		Vehicle Miles Traveled	
Alternative Engine Transportation	Hybrids, Electrics, Hydrogen Fuel Cells …		

3.1 Background

This section provides some background on the case technologies, including a synopsis of how policy affected their development. These cases are explored in much greater depth in other references, which are listed at the end of each case treatment below.

In the technology strategy of *post-combustion emissions control* from electricity generation, two cases were explored that are analogous to carbon capture and sequestration (CCS). Like CCS, both technologies are the highest cost and highest performing (in terms of percentage of pollutant removed) technologies available, and both technologies have been the subject of federal RD&D. Both technologies evolved in the U.S., however, under demand-pull instruments with markedly different levels of stringency.

The first, flue gas desulfurization (FGD) for sulfur dioxide (SO_2) control from coal-fired power plants, is a prime example of a technology subject to relatively stringent "technology-forcing" policy, in the 1970 and 1977 Clean Air Act Amendments (1970 CAAA and 1977 CAAA, respectively) and 1971 and 1979 New Source Performance Standards (1971 NSPS and 1979 NSPS, respectively). These two rounds of national performance-based standards with different degrees of technological neutrality (see footnote 5, above) supported a market for the technology within the U.S. Although it is difficult to separate out innovation based on post-adoption operating experience, FGD provides a clear case in which the labor, maintenance, and supervision costs of installed FGD systems went down with increased technological diffusion. Note that although FGD was an option under the celebrated SO_2 cap-and-trade program under the 1990 Clean Air Act Amendments, the technology had matured in terms of reliability and performance before that program went into effect. For more information on FGD, see Taylor (2001) Taylor (2003), and Taylor et al. (2005b).

In contrast to FGD, the second technology, selective catalytic reduction (SCR) for nitrogen oxides (NO_x) control from either coal-fired (primarily out-of-state) or gas-fired (in-state) generation, is an example of a technology developed outside the U.S. in large part because U.S. policy did not create a market for its domestic use. Despite Japanese experience with the technology dating back to the 1960s, SCR was explicitly ruled out as a technology basis (see footnote 6 for definition) of the 1979 NSPS for NO_x. Instead, the 1979 NSPS for NO_x created a market for lower cost, lower removal technologies in the U.S., and leadership on SCR technology moved to Japan and Germany. By 1992, SCR was installed on 40 GWe of coal-fired power plants around the world, although none of that capacity was in the U.S. That year, the first implementing rules for NO_x of the 1990 CAAA were released, and their stringency was explicitly linked to lower cost and lower removal alternatives to SCR. It wasn't until the 1998 federal NSPS was revised for utility boilers that SCR was considered sufficiently demonstrated to serve as a federal standard's technology basis in the U.S. By this time, world GWe had reached 70 GWe. Note that federal R&D levels reflect the lack of emphasis on SCR technology, with almost two-and-a-half times as much money spent on FGD as SCR.

California was the exception to this "anti-forcing" NO_x policy history when the South Coast Air Quality Management District (SCAQMD) set a rule in 1989 establishing an important niche market for SCR on gas-fired plants in the state. The installation of a large number of SCR units was delayed even in California, however, once the REgional Clean Air Incentives Market (RECLAIM) cap-and-trade program was established and superseded the earlier rule. For more information on SCR, see Taylor et al. (2005d) and Yeh et al. (2005a).

In the technology strategy of *reducing the dependence on fossil fuels of end-use technologies*, the case of solar water heating (SWH) was explored. SWH was subject to a "boom" and "bust" inspired by the commencement and expiration of significant California and federal installation tax credits (1977-1985) as well as a bust in federal R&D (1985 levels were about one-thirtieth of peak levels in 1979). The case of SWH demonstrates the adverse effects of allowing such investment subsidies to expire suddenly and prematurely, as well as the danger of policies that provide incentives for installation rather than performance. The tax credit era was highly successful in promoting the diffusion of new systems, but had a much smaller impact in actually offsetting large amounts of natural gas and electricity for heating water because many of the systems did not work well and were abandoned within a few years (some claim that half of the installed systems were no longer functioning within five years of installation). Experts point to the role of learning-by-doing among system installers during the period of tax credits as the most important driver of essential improvements to SWH technology. Several experts, however, emphasized that the post-tax-credit bust caused these lessons to be lost, rather than codified and retained, in what one veteran called the "tragedy of 1985." As end-use technologies are almost by definition distributed, experience with SWH is widespread in California, even if that experience happened twenty years ago. Although long memories associated with the unreliability of SWH systems are blamed for the general absence of demand for SWH since the bust occurred, Hawaii has recently boosted SWH demand by implementing a capital cost incentive contingent on verification of a system's performance by an inexpensive inspection. For more information on SWH, see Taylor et al. (2005a).

In the technology strategy of *alternative electricity generation*, three cases were explored; two of these cases – wind power (Wind) and solar thermal electric (STE) power – are centralized generating technologies, while the third – photovoltaic (PV) cells – is a distributed technology. Note that wind power is currently the dominant renewable technology at 3-5¢/kWh (a competitive price against fossil fuels), with STE next at about 16 ¢/kWh and PV at 25-30¢/kWh. Meanwhile, STE, PV, and SWH all received much higher levels of public R&D at their peak in 1979 ($300 million in constant $2003), as compared to Wind at its peak (about $160 million in 1975, with a later peak in funding in 1979 of about $130 million).

Wind power was subject to a "boom" and "bust" phenomenon driven by federal and California investment tax credits that was very similar to SWH. As in the case of SWH, 1985 was a particularly bad year for Wind: significant federal and state tax credits expired, the California Public Utilities Commission (CPUC) cancelled generous Interim Standard Offer Number 4 (ISO4) contracts that had provided long-term guarantees of high rates for electricity under the Public Utilities Regulatory Policies Act (PURPA) of 1978, and public R&D reached about a third of peak 1979 spending levels. Also as in the case of SWH, a large number of firms exited the market when the tax credits expired, but unlike SWH, the large number of bankruptcies did not stop innovation; wind power technology significantly improved during the bust. Data on systems installed in California – which basically was the world market for wind power until the tax credits expired – show the capacity factor of systems improving threefold in the five years after the tax credits expired. Wind power was later subject to both federal production tax credits in 1992 and state RPSs beginning in the late 1990s. Although the 2002 California RPS target is one of the highest in the nation (the goal is 20% renewables by 2017), in interviews conducted in 2004, experts attributed the Texas RPS with having the greatest impact on innovation of the various state RPSs. As experts put it, the 915 MWe of new wind power capacity that came online in Texas in 2001 demonstrated that a U.S. market for wind power would really exist outside of California. For more information on wind power, see Taylor et al. (2005b).

In the last few years, some states have tried to encourage solar technologies with solar set-asides in their RPSs. Due to the lower cost of power from STE than PV, this has helped encourage demand in STE for the first time since PURPA removed grid-related barriers to independent energy producers, or qualifying facilities (QFs). PURPA mandated that utilities pay for power from such QFs at "avoided costs," or the costs saved by not having to build new power plants, as well as sell back-up power to QFs at non-discriminatory rates. California, like all states, was given discretion over the implementation of PURPA, and in 1981, the CPUC rewarded QFs with high avoided costs that reflected expectations of high future energy prices. This story was important to both Wind and STE, but STE did not benefit as much from it as Wind because QF plant sizes were originally limited to 30MW or less, which was much smaller than the optimal scale for least-cost STE.[7] Only nine commercial STE plants have been built in the U.S. in the last 30 years. These were all built in California by one company, Luz, which invested over a billion dollars from 1984 to 1991 in building STE plants. Although a federal cost-sharing program with Sandia National Laboratory successfully brought down the operating costs of these STE plants, Luz went bankrupt in 1992. For more information on STE, see Taylor et al. (2005a).

Federal R&D has been the most important government action for innovation in PV in the U.S., although experts rate Japanese and German combined "carrot" and "stick" programs as overall more helpful to innovation, as they succeeded in encouraging an industry to grow and become more competitive. In the past half century, PV has improved more than any other energy technology: costs have declined by a factor of 100 since the 1950s and the electrical efficiency of commercial cells has doubled since the 1970s. Yet the technology remains prohibitively expensive, and with the exception of a few niches, diffusion has been trivial. Although the U.S. has not had much experience with it, there may be an important role for demand-side policies to play in reducing systems' costs. Installation costs are currently significant ($1-$2/W), and the highly site-specific way in which systems are installed suggests that there is a large opportunity for learning-by-doing by systems installers. To avoid "white-elephants," subsidies should be performance-based; for example, capital cost incentives can be made contingent on verification of operation, as in the recent Hawaiian SWH program. For more information on PV, see Taylor et al. (2005a).

Finally, in the technology strategy of post-combustion emissions control from traditional automotive engine transportation, the case of automotive emission controls (AEC) was explored. Over the past three decades, California emission control requirements generally have been the most stringent in the nation, often serving as a model for subsequent federal and state standards.

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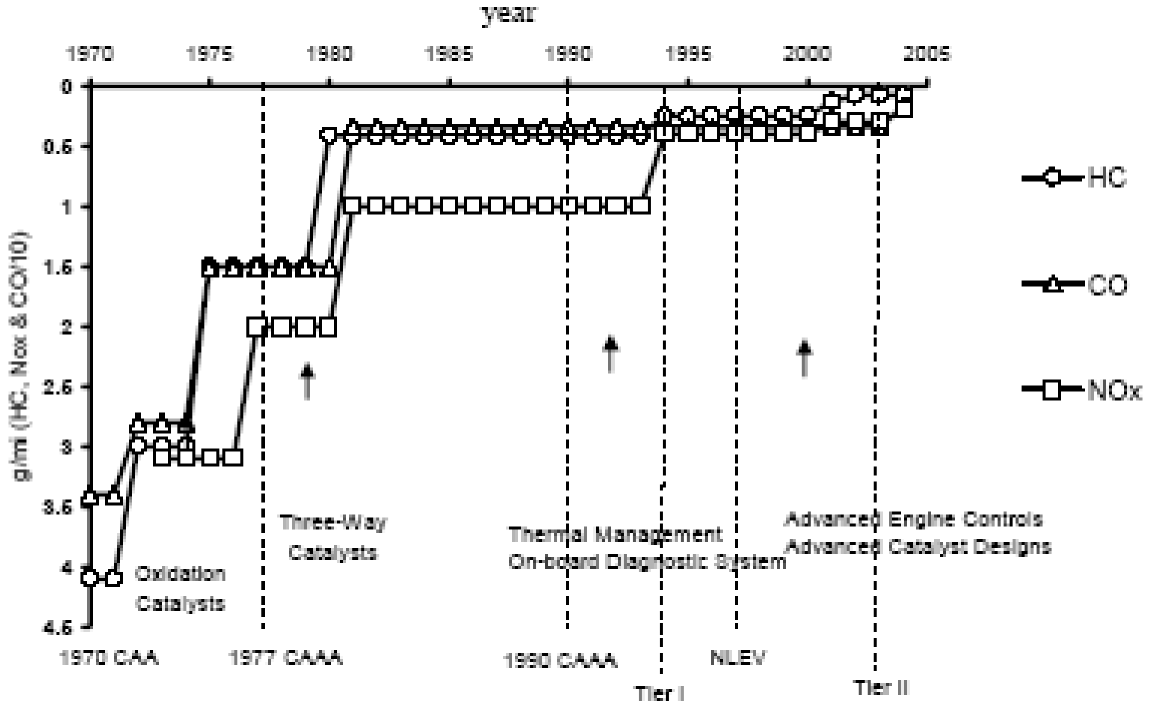
[7] The QF size was later modified to 80 MWe, but that was still smaller than the optimal size experts related to us of 200 MWe.

The first automotive emission controls date back to 1961, when automakers voluntarily began installing positive crankcase ventilation (PCV) valves on all new cars sold in California to control emissions from crankcase blowby. Within several years all new cars sold in the U.S. were equipped with this inexpensive device. In 1966, California adopted a more comprehensive set of emission control requirements that included evaporative and tailpipe emissions standards based on a standard driving test cycle developed in the state. The California standards subsequently were adopted nationally, beginning with 1968 model year cars and light-duty trucks. Figure 3-4 displays changing federal automotive emission standards between 1970 and 2004, which have been the dominant type of policy interacting with environmental innovation for AEC. The figure also documents the major innovations that occurred with these controls over time. For more information on this distributed technology, see Lee (2005) and Lee et al. (2004).

Figure 3-4. Federal automotive emission standards, 1970–2004.



Source: Lee et al. 2004.

Table 3-2 summarizes the fact that not one of these seven technology cases is subject to only one type of government action; this is a helpful reminder of the complexity of the government role in environmental innovation. The breadth of studies collated in this chapter, however, means that no government action is limited to appearing in only a single case; this comparative perspective provides some helpful insights when considering California climate change policies.

Table 3-2. Technologies studied in this chapter and the government actions that were important to their development

Government Action	Observation						
	FGD	SCR	Wind	PV	STE	SWH	AEC
Regulatory: Performance-based standard	✓	✓					✓
Regulatory: Cap-and-trade program	✓	✓					
Investment subsidy: tax credit, rebate			✓	✓	✓	✓	
Production subsidy: rate guarantees, production tax credit			✓	✓	✓		
Renewable portfolio standard			✓	✓	✓		
Federal RD&D	✓	✓	✓	✓	✓	✓	✓

4 Major Findings

4.1 Observations Across Cases

This section lists ten major observations about policy and environmental innovation that we found in at least two or more cases and believe may be particularly helpful in considering the innovation-inducing aspects of the policies California may undertake to meet the 2050 GHG emission targets.

1. Innovation occurs in environmental technologies.

In all cases but SWH, the capital costs of the technology went down as the technology diffused (see Figure 3-5 and Figure 3-6 below), and except for STE, those cost changes were significant. A hypothesis for some of the slight increase in SWH costs, as yet untested, is that the "tragedy of 1985" brain drain, in which systems installation knowledge was lost, rather than codified and retained, was a source of "organizational forgetting." In addition, the slow rate of STE cost improvement may relate to the importance to these improvements of economies of scale (recall that qualifying facilities under PURPA were much smaller than the optimal scale for least-cost STE).

At the same time that costs have improved in most of these technologies, the performance of all these technologies has also improved.

2. Technologies do not become competitive overnight.

There are usually problems with the early installations of immature environmental technologies. Examples include the plugging and scaling of FGD systems in the 1970s, some of the exotic wind turbine designs in California in the early 1980s, and early failures such as freezing pipes and related leaking roofs associated with the rapid installation of a large number of SWH systems in California (there was also clearly fraud in the SWH case, as sellers overcharged and shared the rebates with consumers).
These sorts of early "field" problems are often worked out through incremental innovations that occur post-adoption. A rough rule of thumb, based on these cases, is that policy-makers can expect this process to take about ten years.

3. Patenting activity in environmental technologies appears to respond to demand-pull policy events.

This observation holds, to varying degrees, in all seven cases. The most rigorous analysis of this finding appears in Taylor et al., (2005c), which describes the two patent search strategies used in the FGD case (that have also been used for each of the others), as well as the econometric approach taken in that paper to compare patenting activity against demand-pull as well as technology-push government actions. Lee (2005) also details a statistical analysis of AEC patents that indicates that patenting activity increased significantly both in response to, and in anticipation of, new emission control requirements (anticipation was also a factor in the FGD case). Time constraints involved with this report have not allowed for a full econometric analysis of the other cases, but the visual patterns expressed by the data are difficult to argue against in this context. Indeed, in each case, the majority of experts interviewed confirmed that the patterns of patenting activity were to be expected based on the market conditions established by demand-pull instruments.[8]

Finally, it is important to mention that the stringency of emission control requirements appear to have been the key driver of AEC control technology innovation, as well as patenting activity in FGD and the diffusion of both FGD and SCR.

4. Cap-and-trade programs are not a magic bullet for the innovation problem.

It can be argued that there are two problems in meeting the 2050 targets, one a pollution problem, and the second an innovation problem. Although cap-and-trade programs have proven effective in dealing with the first, they are not a magic bullet for dealing with the second.

Two cases, FGD and SCR, were options under cap-and trade schemes (FGD under the 1990 CAAA and SCR under California's RECLAIM program). As explained in Taylor et al. (2005b), the weight of evidence in innovation in SO_2 control technology does not support the superiority of the 1990 CAAA – the world's biggest national experiment with emissions trading – as an inducement for environmental technological innovation, as compared with the effects of traditional environmental policy approaches. Repeated demand-pull instruments, in the form of national performance-based standards, along with technology-push efforts, via public RD&D funding and support for technology transfer, had already facilitated the rapid maturation of FGD technology. In addition, traditional environmental policy instruments had supported innovation in lower cost, lower removal alternative technologies, such as dry FGD and sorbent injection systems, which the 1990 CAA provided a *disincentive* for, as they were not as cost-effective in meeting its provisions as low sulfur coal use combined with limited wet FGD application.

In the case of SCR, meanwhile, experts involved with the California RECLAIM program state that it delayed the implementation of SCR technology in California by ten years, when compared to what the performance-based standard of SCAQMD rule 1135, issued in 1989, would have done.

5. Subsidies and subsidized industries are prone to instability.

In a capitalist system, subsidies are subject to budgetary wrangling, as the public does not want to support a non-competitive industry forever. Performance-based standards are much clearer demand signals for industry, as regulations tend to get stricter rather than expire like a subsidy. Renewable portfolio standards also send a clear demand signal to industry.

In two technology cases, Wind and SWH, large federal and state investment incentives set off a "boom" and "bust" phenomenon. Although the installation boom associated with these investment tax credits was helpful to the diffusion of each technology, unfortunately, that boom was not tied to high-performance technology. Meanwhile, the industry bust that followed the

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[8] Although a measure of the output of inventive activity, patents are also important to the understanding of adoption and diffusion as inventors typically file patents because they expect to market their inventions.

expiration of significant tax cuts resulted in both cases in bankruptcies and a disruption in the innovation process. In Wind, production tax credits have proven more stable than investment tax credits, although they too have expired at inopportune times.

Another problem with subsidies occurs in the case of "buy-down" subsidies that tend to increase the prices of installed systems even while the costs to produce them decline. Giving rebates to consumers for the purchase of systems, such as PV, increases their overall willingness-to-pay since they only have to pay a portion of the system price. These subsidies therefore have the effect of shifting the demand curve for PV systems upwards. This theoretical observation is corroborated by recent market data. For example, the prices of installed PV systems in California increased in 2001 when the buy-down rebates were increased to $4.50/W. Similarly, PV prices in Germany have increased in the past two years as the federal "Renewable Energy Law" has guaranteed tariffs of greater than 50¢/kWh. In both of these cases, the prices of installed systems rose while the cost to produce the underlying components declined.

6. California can start the innovation process by creating a niche market.

California has been a leader in most of the technologies studied for this report, including SCR for gas-fired plants in the U.S., Wind, STE, SWH, and AEC. Although the full extent of the value to California of this leadership role is unclear, patent analyses indicate that California is capturing a greater share of intellectual property in many of these industries – 18.1% of the patents in Wind, 14.2% of the patents in SWH, 22.9% of the patents in STE, and 14.5% of the patents in PV – than in the patent system as a whole (8.7%).[9]

7. The technical perception of unreliability is problematic for diffusion and policies to spur diffusion, particularly if the audience familiar with the reliability problems is large.

An example of this is a comparison of early FGD systems, a centralized technology with reliability problems in the 1970s, to early SWH systems, a distributed technology with reliability problems in the 1980s. In the case of FGD, unreliability led to litigation and was an important factor behind why NO_x standards were not set at a stringent enough level to promote the diffusion of SCR technology in the late 1970s. Still, FGD matured and continued to be supported by public R&D and repeated demand-pull instruments.

In the case of SWH, on the other hand, many of the systems did not work well and were abandoned within a few years. Despite technical improvements that overcame these early problems, the perception of SWH as technically unreliable persists both among policy makers and consumers. Hawaii has recently overcome this problem, however, by coupling an inexpensive inspection program with the rest of its inducement policies.

8. Post-adoption innovation is important.

As mentioned in number two, above, there are usually problems with the early installations of immature environmental technologies, and these problems are often overcome with incremental

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[9] The AEC case has not looked at this intellectual property ownership issue yet.

innovations that would not have been possible without “field” experience. In FGD, Wind, STE, and SWH, post-adoption technical improvements were very important to making these technologies competitive. Demand-pull instruments are therefore particularly important in providing the opportunity for these improvements to take place. Note that PV may be ripe for gaining some of the benefits of post-adoption innovation, due both to its technical characteristics as well as to California’s will to diffuse the technology broadly.

9. Technology-push instruments, in the shape of public support for RD&D, are helpful in environmental innovation, but in cases where demand-pull instruments also exist, the combination is stronger than RD&D support alone.

On the “technology push” side, all the cases have benefited from government support for RD&D. This support has been effective in the past at everything from supporting “basic” fundamental research (PV comes to mind, as do selective coatings for SWH) to supporting “applied” research that has helped lower the operating costs and increase the performance of particular technologies (STE is a good example).

“Technology-push” instruments, however, appear to work best in combination with “demand-pull” instruments. In FGD, for example, despite long-standing public RD&D for SO_2 control, patenting activity does not occur at significant levels until after demand-pull instruments are initiated. Further, for the cases of PV and Wind, the combination of foreign technology-push and demand-pull instruments has been praised by experts in interviews as particularly important for innovation. Demand-pull instruments provide innovators with a commercial interest for researching a technology that public support for RD&D cannot meet.

Note that although full analysis of these cases is not yet complete, it appears that public RD&D support in the energy technology cases tends to correlate with other policy events (e.g., rulemakings, tax credit expirations, etc.), although the visual pattern of patenting activity for renewables appears to move in greater lock-step with public R&D funding than patenting activity for pollution control technologies.

10. Government support of knowledge transfer esp. important.

Government has been effective in every case in supporting the transfer of knowledge between innovative actors through such low-cost and high-impact activities as sponsoring regular stakeholder conferences.

4.2 Experience Curves

For each technology case study, we have constructed experience curves. Figure 3-5 consolidates the capital cost experience curves from the 1970s until the early 2000s of six of these technologies, with both axes on logarithmic scales. The x-axis in Figure 3-5 represents world cumulative installed commercial capacity in megawatts (MWs), except in the situation of SCR for gas-fired plants. The y-axis represents the cost of installing new systems in dollars per Watt ($/W) of capacity; all values in this figure have been converted into constant 2004 dollars. The lines shown in the figure are power functions which best fit the available data points using the functional form described in the climate modeling and technological change literature section on experience curves earlier in this chapter. A power function plotted on logarithmic axes appears as a straight line.

The larger the learning rate, the more a technology declines in cost with each additional unit of new capacity. For example, a learning rate of 0.10 means that the cost of that technology will decline by 10% for each doubling of installed capacity. We calculated learning rates for each of our cases and found that they cluster in three groups. In the first cluster, PV and Wind had the highest learning rates at 22.9% and 16.8% respectively. Both of these technologies have benefited from economies of scale in larger PV manufacturing plants and larger wind turbines.

In the second cluster, SCR has a learning rate of 12.6% and FGD has one of 9.6%. AEC fits into this cluster, although this case could not be displayed in Figure 3-5 because of differences in the x- and y-axes from the rest of the cases. Figure 3-6 displays the cost trend for emission control systems during the 1980s, when emission standards remained stable for about a decade. Figure 3-6 shows that costs declined about 7% for each doubling of capacity. These data exclude the cost of precious metal catalysts, whose prices rose during that time (Lee 2005).

In the final cluster, technological change was less favorable to capital costs. STE plants declined in cost at the rather slow learning rate of 3.4%. Solar water heaters, on the other hand, actually increased in cost; SWH had a negative learning rate (-4.3%). Several of our expert interviewees pointed to the increases in materials and labor costs that pushed up the costs of these systems. The extremely modest technical improvements in SWH in the 1980s and 1990s were unable to overcome these cost increases that almost certainly affected other technologies as well (materials costs were only controlled for in the AEC case, as mentioned above). Other contributing factors to the negative learning rate in SWH include: (1) the loss of tacit knowledge among SWH installers that followed the bust at the end of tax credits in the mid-1980s, and (2) the inefficient manufacturing scale that surviving firms had to operate at following this bust.

Figure 3-5. Experience curves for six technology cases, according to cumulative installed capacity around the world and $/W capital costs (2004 dollars).

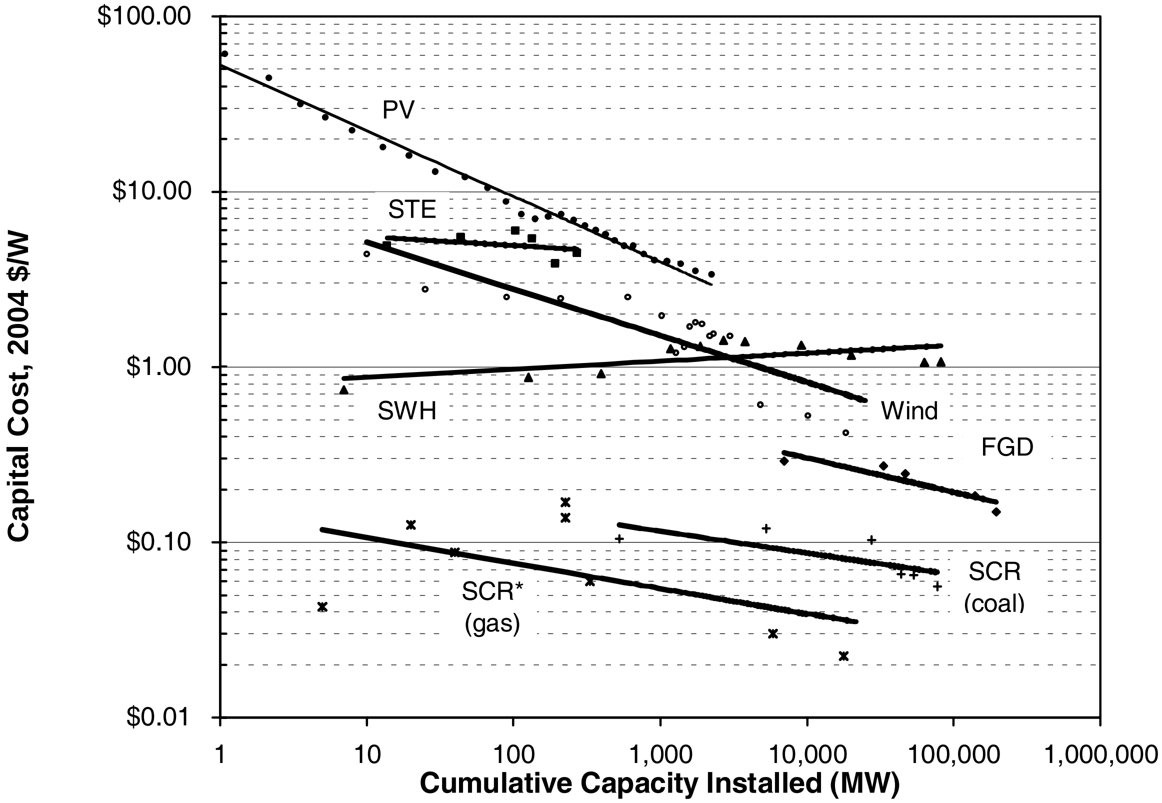
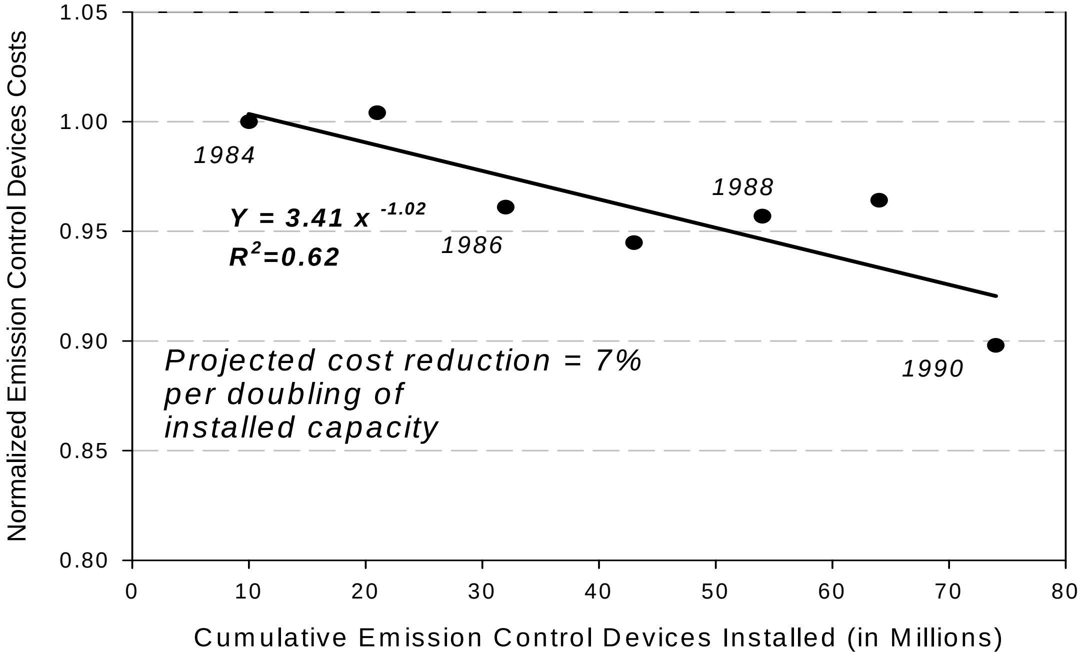


Figure 3-6. Normalized experience curve for non-catalyst components of AEC system.



Source: Lee (2005).

As mentioned in the climate modeling and technological change literature section on experience curves earlier in this chapter, several studies have criticized experience curves for lumping together a number of different cost-reducing and technology-improving phenomena under the umbrella of learning from "experience." Dutton and Thomas (1984) showed a wide variation in learning rates in 108 different learning curve studies, and Argote and Epple (1990) proposed four alternative hypotheses to explain this variation in technical improvements: economies of scale, knowledge spillovers, organizational forgetting and employee turnover. Nemet (2006) has continued in this tradition by delving underneath the experience curve for PV technology. Table 3-3 reveals the factors underlying the cost of PV.

Table 3-3. Factors explaining the cost of PV. Source: Nemet (2006).

Factor Cost	Impact (%)
Plant size	43
Efficiency	30
Silicon cost	12
Wafer size	3
Si use	3
Yield	2
Poly share	2
Other factors	5

The opportunity of innovators to capitalize on the potential of these factors can be influenced by the details of policy. If the Nemet (2006) ratios for PV were assumed true for the case of STE, for example, the PURPA limitation of QFs to 30 MWe and smaller installations discussed above would clearly limit opportunities for capitalizing on economies of scale. This is only one example of how detailed technical knowledge can inform policy makers faced with difficult design decisions in GHG emissions reduction.

4.3 Implications for California Policy

To reach the 2050 GHG emissions goals, significant innovation is likely to be required, particularly in environmental technologies that play a vital role in maintaining the "public good" of a clean environment. The analysis in this chapter shows that innovation in environmental technologies occurs, although it can occur slowly. It also shows that certain types of government actions tend to support environmental innovation more effectively than others, which is an important consideration in this area of innovation in which private investment incentives are lacking.

Based on the analysis done in this chapter, it appears that a combination of policy instruments – both "technology push" and "demand pull" – will offer the greatest chance of successfully inducing the innovation needed to meet the 2050 GHG emission targets. On the "technology push" side, government support for RD&D has been effective in the past, at everything from supporting "basic" fundamental research to supporting "applied" research that has helped lower the operating costs and increase the performance of particular technologies. Government has also been particularly effective in supporting the transfer of knowledge between innovative actors through such low-cost and high-impact activities as sponsoring regular stakeholder meetings.

“Demand pull” policies have included performance-based standards, cap-and-trade programs, investment subsidies, production subsidies, and renewable portfolio standards. Choosing among them for innovation purposes should be based on the clarity of the market signals they provide to innovators, including: (1) how they incentivize the highest level of performance of a technology (in pollution control, for example, this would be regulatory stringency)[10]; (2) how they provide opportunities for technologies that compete against each other to achieve an environmental goal via different technical approaches (this is technological flexibility or neutrality); (3) how certain and stable the market signals they provide are, so that strategic thinkers in innovating companies can plan to meet future demand; and (4) how they incentivize the co-development of technical mechanisms for verifying performance.

The advent of “demand pull” policies in the past has corresponded with both peaks in patenting activity and the diffusion necessary for inspiring post-adoption innovative activity that has proven itself to be important to every case of environmental innovation studied in this chapter. Still, cautions need to be made about adopting certain demand-pull policies.

First, subsidies have provided unstable demand signals to innovators in the past, and may be best to avoid unless they can be guaranteed over at least modest timeframes. One innovator interviewed for this chapter made a specific request on this subject, namely that for planning purposes, he’d “rather have a lower rebate, say 15%, guaranteed for 5 years or more, than a large rebate, even more than 40%, that might last only a year or two.”

Second, cap-and-trade programs in the past have not proven as effective in inducing innovation as proponents might have wished. Such programs can be designed to be more effective in supporting innovation if they incorporate some of the best features for innovation of traditional performance-based standards, namely by being stringent enough to require innovation (a provision that makes safety valves seem to be a bad idea, on first consideration), timely enough not to delay diffusion of technology and subsequent improvements based on operating experience, and by not standing alone in the minds of policy-makers as sufficient for innovation.

A plausible alternative to a cap-and-trade program would be a repeated issuance of performance-based emissions reduction standards in particular sectors of the economy. This could be done at well-spaced intervals (to incorporate both near-term booms in inventive activity and post-adoption technical improvements) that are known by innovative actors as certain. The standards could further be based on the best technology available and projected at a given time, thereby providing a timely, technologically flexible yet gradual and certain approach to continuously incentivizing innovation in climate-relevant technologies.

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[10] A lack of regulatory stringency has also proven to be a drag on innovation. Whereas performance-based standards for SO_2 control were set stringent enough to diffuse FGD in the U.S., similar standards for NO_x control were not stringent enough to promote SCR in the U.S., despite early public R&D in the technology and the diffusion of SCR internationally.

It is important to remember, however, that if a technology is not quite mature – and there are often problems with first generation technologies – the politics of public support for continued progress with these technologies appears easier to finesse when the technology is not distributed, as in the case of solar water heating. Perceptions of unreliable systems are difficult to overcome, as has been the case in California with this technology. One effective solution has been a Hawaiian program in which capital cost incentives are made contingent on verification of systems performance.

California has proven itself as a leader in environmental innovation in the past. This leadership role is clear in GHG emissions profiles, technology histories, and even in patenting proportions in renewable energy technologies. With its new GHG emissions targets, California is likely to be an innovative environmental leader well into the future.

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