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Stimulating 'green' technological innovation: An analysis of alternative policy mechanisms

VICKI NORBERG-BOHM
Environmental Policy Group, Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.
E-mail: vnb@mit.edu

Abstract. As our understanding of human impacts on the environment has increased, it has become clear that we need to move toward a closed-loop industrial society in order to avoid undesirable health and ecosystem consequences. Achievement of this goal depends on radical technological innovation in both products and processes. This paper explores how to design public policy mechanisms to stimulate rather than impede pollution-preventing technological innovation. It begins with a discussion of the role of government in civilian technology development and diffusion. It then sets out six design criteria for policy to promote 'green' technology innovation. Based on this set of design criteria, the article assesses the potential and limitations of current U.S. policy approaches to stimulate technological innovation that moves us toward a minimal waste society. The main conclusions of this assessment are as follows. Over the past decade, the U.S. environmental policy system has experienced a variety of reforms and new initiatives, many aimed directly at promoting environmentally-friendly technological change. The strengths of these reforms are to increase the information that the private sector has about the magnitude and cost of their environmental impacts and to allow greater flexibility in the technologies that firms choose to meet environmental regulations and goals. Because of these reforms, firms are likely to undertake technological innovation for the environment in situations with clear short-term economic benefits, i.e. to capture the much heralded win-win potential of environmental regulation. However, these reforms have significant weaknesses as well. Unless policy provides stronger political or economic incentives and clearer signals about future environmental performance requirements, we are unlikely to be able to drive technological innovation in industries where the pay-off is more longterm or uncertain, and thus will make only limited progress toward the goal of a minimal waste society.

Introduction

The management of many current and emerging environmental problems will require significant reductions, if not total elimination, of the emission of environmentally harmful chemicals. In recent years we have seen the phase-out of ozone depleting chemicals and a growing consensus that deep cuts in greenhouse-gas emissions will be required to minimize the risks from climate change (Parson, 1996). Concerns about immune system and endocrine toxicity, although still the subject of much uncertainty, suggest there may be a need for deep reductions in the emissions of persistent organochlorine compounds to the environment (Colburn, Dumanoski et al., 1996; Amato, 1993). The Netherlands National Institute of Public Health and Environmental Protection concluded that the emissions of many industrial pollutants need to be reduced by 70–90% by the year 2010 to avoid environmental disaster (Langeweg, 1989). The need to

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significantly reduce emissions associated with production and consumption becomes even clearer when we consider the increased human activity that will be brought about by population and economic growth. Putting together a vast array of indicators which each in themselves suggest the environment can no longer be used as an unbounded repository of industrial society's wastes leads to a vision of a 'closed-loop' industrial society.[1] This goal has been popularized, by the President's Council on Sustainable Development amongst others, as the goal of a 'zero waste' society (Sustainable Development, 1996).

Zero wastes is an illusive goal, and a potential object of scorn, in that it is not thermodynamically feasible. However, it points us in the direction of the achievable goal of a 'minimal waste' society. The vision of a minimal waste society suggests the need for very low levels of waste generation and low toxicity and persistence in the wastes that are generated. It challenges firms to focus not only on how to meet current and emerging regulations for particular 'bad actor' chemicals, but to re-think the design of future products and manufacturing processes. To accomplish this, firms must to a large extent forego end-of-pipe approaches to managing the environment, replacing these with an integration of environmental concerns into the design of products and processes. More broadly, it challenges society as a whole to focus on minimizing environmental impacts throughout a product's lifecycle – from primary materials extraction through manufacturing, use, and disposal.

A variety of terms have been used to describe this new focus on reducing rather than controlling pollution, including pollution prevention, eco-efficiency, resource productivity, and industrial ecology. What is relevant for this paper is not the definitional distinctions amongst these terms, but rather the fact that they all suggest the need for a fundamental industrial transformation that in turn will depend on radical technological innovation.[2] The focus of this article is on how to design public policy to stimulate rather than impede the required innovation. I begin this exploration with a discussion of the role of government in technological change. I next turn to a set of design criteria for policy to promote technological innovation for the environment. The bulk of this article assesses the potential and limitations of current U.S. policy approaches against this set of design criteria.

Over the past decade, the U.S. environmental policy system has experienced a variety of reforms and new initiatives, many aimed directly at promoting environmentally-friendly technological change. As will be discussed below, the strengths of these reforms are to increase the information that the private sector is developing about the magnitude and cost of their environmental impacts and to allow greater flexibility in the technologies that firms choose to meet environmental regulations and goals. Because of these reforms, firms are likely to undertake technological innovation for the environment in situations with clear short-term economic benefits, i.e. to capture the much heralded win-win potential of environmental regulation. However, these reforms have significant weaknesses as well. Until policy is able to provide stronger incentives for 'green' technology innovation and to reduce long-term uncertainties, we are

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unlikely to be able to drive technology innovation in industries where the pay-off is more long-term and uncertain, and thus will make only limited progress toward the goal of a minimal waste society.

The government's role in technological innovation for a minimal waste society

Technological innovation is only one part of the larger process of technological change, which encompasses invention, innovation and diffusion. Before discussing the government's role in innovation, it is worthwhile to discuss the differences in these three components of technological change. Inventions are new technical ideas or devices. Innovation is the first commercial or practical use of an invention. Diffusion is the adoption of innovations by others. The government's role in invention is fairly straight forward: funding of basic science and technology and protection of intellectual property rights. Although still not without difficulties, as will become clear in this analysis of U.S. environmental policy, we currently have a greater understanding and more practice fostering diffusion than innovation. Thus, the focus of this paper is on the design of public policy to stimulate innovation. More specifically, it focuses on policy to promote innovation that reduces environmental impacts through waste minimization, thus moving us toward the goal of a minimal waste society. Throughout this article, I will refer to this as 'green' or 'environmentally-friendly' technological innovation. This article is further delimited to focusing on policies for creating a demand for technology innovation, for reasons discussed below.

Government policy for promoting innovation includes efforts to increase both the supply of and demand for innovations. Policy mechanisms for increasing the supply of innovation include investment tax credits, and funding for research, development and demonstration. Demand-side measures include standards, economic incentives, procurement and information-based programs. To date, the largest government efforts to promote technological innovation have been in big science programs, such as the defense and space programs. The general conclusions of analysts who have examined these programs is that success depended on the government enacting simultaneously policies that influenced both the supply of and demand for technology. This was accomplished largely through government procurement programs when the government had a monopsony or oligopsony, i.e. was the only major procurer (Mowery and Rosenberg, 1979; Walsh 1993; Dalpé, 1994; Katz and Phillips, 1982; Levin, 1982; Mowery and Rosenberg, 1982). Because the government was both the key funder of R&D, as well as the exclusive, first and/or main user of these products, there was continuous communication between the innovator (manufacturers) and the consumer (government). In this setting, the government was able to play the role of an intelligent consumer, providing timely feedback and the opportunity for directed improvements as the technology evolved (Rothwell and Zegveld, 1981; Nelson, 1982).

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There are considerable differences between the big science projects and technological developments for the environment.[3] First, environmental technology is not actually a separate category of technology. Rather, the goal of a minimal waste society requires integrating environmental concerns into all technology development. Second, in the environmental realm, the government is generally not the main consumer, and thus not in a position to coordinate supply and demand as it did in the case of the military and space programs, nor is it in a position to guarantee a market. Finally, unlike the defense program and the early years of the space program, we lack a national consensus behind the level of environmental protection that is desired, or the need for a government role in technology generation.[4] These knowledge, market and political barriers limit government supply-side initiatives. Although government will continue to play a role in technology generation, its larger role will be in fostering private-sector demand for technological innovations that benefit the environment.[5]

Design criteria for policy for 'green' technological innovation

The ability to create environmentally-friendly innovations lies largely within the private sector. Public policy is one of many variables that can influence the rate and direction of technological innovation. Other key factors include: industry structure, factor prices, technological trajectories and histories, consumer demand, corporate organization and management, societal norms and leadership preferences and aspirations. Environmental regulation influences technological innovation by changing some of these other key variables, for example, when standards or environmental taxes change factor prices. Four characteristics of environmental policy that have the ability to change the other factors that influence innovation and thus to stimulate green innovation are the ability to: (1) stimulate industry-generated information; (2) provide economic or political incentives; (3) reduce long-term uncertainties; (4) provide flexibility.[6] Two additional design characteristics are necessary to insure that innovation moves toward the goal of a minimal waste society: (5) a multi-media approach and (6) consideration of the full product lifecycle. This analysis does not suggest that all six design characteristics must be met, but that policies meeting more of the criteria are more likely to stimulate 'green' technological innovation. Further case investigation is likely to yield a fuller understanding of the conditions under which each of these characteristics are most important.[7]

To motivate firms to use their innovative ability to achieve better environmental performance, firms must develop a clear understanding of their environmental impacts and their current costs for managing those impacts. Historically, most firms have not focused their innovative energy and resources on technological innovation for the environment, instead absorbing pollution control costs as overhead, thinking of them as simply another cost of doing business. More recently, firms that have developed information about their environmental

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impacts and costs have identified and invested in many win-win opportunties, reducing pollution and costs simultaneously (Schmidheiny, 1992; Smart, 1992; Ditz, Ranganathan et al., 1995). Public policy can play a significant role by either requiring or motivating firms to develop more information about their emissions and opportunities for pollution prevention.

Forward-looking and technologically oriented firms may find information a strong stimulus to greater innovation for the environment, especially in win-win situations. But in cases where the pay-off is less certain or longer-term, firms may need incentives that change their competitive environment, making it good for the bottom-line to innovate. Market mechanisms, such as taxes, can provide a direct economic incentive. Other policies, such as standards that restrict the use of the environment for the disposal of wastes and provide penalties for non-compliance and programs that disseminate information which results in public pressure for environmental improvement and/or public demand for environmentally sound products, can also impact the competitiveness of corporations, and thus provide direct incentives for innovation. In sum, both economic and political incentives can create a market for green technological innovation.[8]

Because innovations may take a long-time to develop, private investment in R&D for the environment will be enhanced by reducing long-term uncertainties in the demand for environmental improvement. Firms have traditionally made longer-term investments in innovation only in their core business, and not for environmental protection. To the extent that the generation of new knowledge has made firms aware of the win-win potential in the environmental area, they will carefully assess the market for innovation. While there can be first-mover advantages, in cases where investments in innovation may only be recouped over the long-run and/or with significant market penetration, firms must worry about being ahead of the market for these 'green' innovations (Porter and van der Linde, 1995). To the extent that policy creates a societal commitment to continual environmental improvement, i.e. sends a message to firms that over time they will have to increasingly internalize their environmental externalities, we are more likely to see innovative efforts directed toward waste minimizing technologies.

Reducing uncertainty needs to be coupled with flexibility, concepts that are only superficially contradictory. Uncertainty in the level of environmental protection needs to be reduced while providing flexibility in meeting environmental policy goals. Because the ability to innovate lies within the firm, and because government is not generally successful at picking commercial technology winners and losers (Roessner, 1984: p. 245; Nelson, 1982: pp. 469–470), an innovative policy will allow firms to respond with any technology that meets the environmental goal. Flexibility is a challenge for policy because of the difficulties in enforcing flexible policies, although there is evidence that it can be successfully managed and provide an important stimulus for innovation (Becker and Ashford, 1995; EPA, 1993).

These first four characteristics – information, incentives, reduced uncertainty

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and flexibility – are important for innovation in general. The final two – a multimedia and lifecycle approach – must be added to the list to assure that innovative efforts are moving toward a minimal waste society. Policies that are single-media are likely to result in fragmented responses in which firms move pollutants from the air and water to the land. A multi-media perspective, which asks firms to consider all environmental impacts simultaneously is more likely to stimulate green technological innovations, as the shifting of pollutants is illuminated and also because the total cost of a large number of single, end-of-pipe treatments becomes clear.

Consideration of the product lifecycle is equally important in moving toward a minimal waste society. A lifecycle perspective forces a range of innovations to be considered simultaneously, and to be evaluated against the impacts during all phases of a product's life, including production, use and disposal (Graedel and Allenby, 1995: pp. 93–182). This can be best explained through an example, such as household appliances. Clearly re-use, re-manufacture and recycling are important to prevent land-based disposal, but design for the environment should not overlook the key environmental impacts of these products, which take place during use, e.g. energy and water use and associated pollutants.

Assessment of current U.S. environmental policy as a stimulus for 'green' innovation

There are a variety of environmental policy mechanisms that can create demand for technological change. These include standards, as well as newer approaches such as market-based mechanisms, information generation and dissemination, voluntary compliance, industry councils, and product stewardship policy. Arguments have been made regarding the effectiveness of each of these policy mechanisms in promoting innovation. This assessment suggests that each approach has both strengths and weaknesses, with the effectiveness of these mechanisms in promoting innovation dependent on the details of their specific usage.[9] The goal of this assessment is twofold: (1) to evaluate whether the manner in which these policies have been employed in the U.S. has created the six conditions necessary for 'green' innovation; and (2) to discuss how the use of these mechanisms could be modified to increase the stimulus they provide for innovation.

The results of my assessment of current U.S. practice are summarized in Figure 1. This matrix is a visual representation of the degree to which each of five policy mechanisms, as currently practiced, create the conditions required to stimulate technological innovation. One exception to a focus on the U.S. is in the case of product stewardship policy. Because there has not been significant experimentation with this tool in the U.S., I draw instead on Germany's experience with product stewardship for packaging. Below I introduce the approach to ranking used to create this matrix and discuss the key conclusions of this study. These results are supported by the more detailed assessment contained in the remainder of this article.

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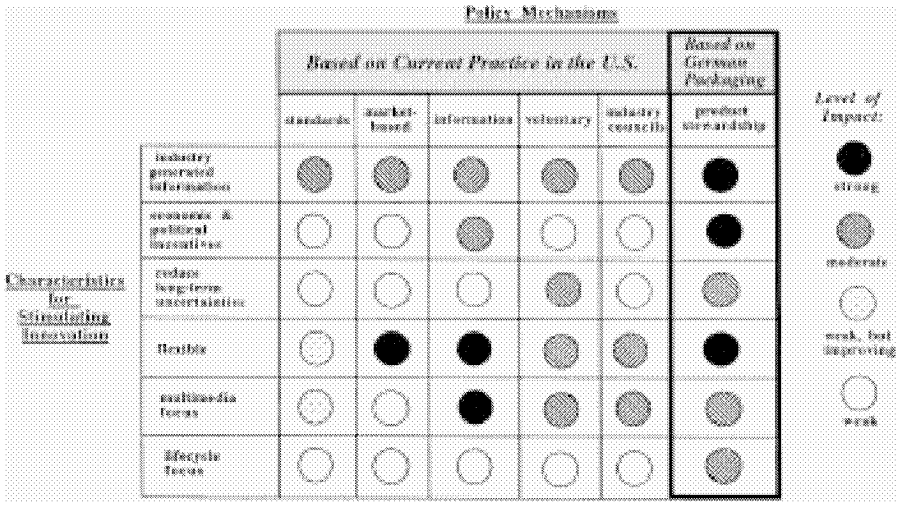

Fig. 1. Effectiveness of alternative policies for promoting technology innovation.

In evaluating the extent to which each policy mechanism has, in practice, satisfied the six conditions for stimulating 'green' innovation, I have used three major categories: weak, moderate and strong. A fourth category, weak but improving, was also used in two instances. This is an admittedly imprecise approach. One of the key difficulties in assessments of this type is aggregation, as some of these mechanisms have been used extensively and with varying results. If each instance of use had been judged separately, one would find a range of rankings for many of the mechanisms. The effort in this paper is to portray the usual outcomes. Outliers provided insights into how to improve the effectiveness of each mechanism.

Despite its shortcomings, this approach to assessing policy for innovation serves three purposes: (1) it provides a systemic way to examine the comparative strength and weaknesses of different policy tools, (2) it provides a basis for considering improvements in the design and implementation of specific policy tools, and (3) it allows us to examine how different tools might be effectively employed in combination to create all six conditions necessary for promoting innovation.

The traditional standards-based approach to regulation, not surprisingly, has not been effective in meeting the full range of criteria for stimulating innovation. Based on this failure, the EPA, corporations, and environmental activists have looked to alternative strategies for promoting pollution prevention.[10] These newer approaches to policy satisfy more of the criteria for stimulating innovation. However, even these policies show considerable limitations. First, the existence of few 'strong' scores on the matrix suggests that the policy innovations as practiced need further refinement to promote innovation. Second, the greatest strength of the U.S. approach is in stimulating industry generated

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information. This is likely to result in significant diffusion and the capture of near-term win-win opportunities, but alone will generate only limited innovation. Third, none of the policy mechanisms that are currently being experimented with in the U.S. meet as many of the criteria as product stewardship. Fourth, further innovation in policy will be needed to fully consider lifecycle issues.

Standards

The U.S. environmental policy system is largely a standards-based system, including ambient and performance standards.[11] Ambient standards set pollutant limits for particular components of the ecosystem, with limits based on controlling health or ecosystem risk. Performance standards set limits on pollutant discharches for a particular pollutant and industry, and are generally based on a 'best' technology. Ambient and performance standards are often used in combination, with performance standards setting a baseline of pollutant emissions for particular sources and ambient standards being used to ensure that health and ecosystems are protected, sometimes requiring reductions in pollutants beyond those required by a performance standard. In addition, the U.S. has occasionally promulgated product bans as a way of meeting environmental goals. Performance standards are the most common policy mechanism used in the U.S. An OTA study of 32 major programs under the Clean Air Act, the Clean Water Act and the Resource and Recovery Act found that performance standards were used in 75% of the programs, while ambient standards were used in 50% and product bans in about 10% (OTA, 1995: p. 4).

Standards have in most instances not stimulated radical innovation in pollution prevention technologies (Ashford, Ayers et al., 1985). Some notable exceptions have been product bans, such as PCBs and CFCs. There are three reasons why performance standards have been a limited force for green innovation. First, standards are generally based on existing technology, and thus promote diffusion rather than innovation (Ashford, 1994, p. 298). Second, the permitting process presents an obstacle to innovation. Standards are implemented by requiring polluting entities to obtain a permit to pollute and are issued when a source is in compliance with applicable standards. Although firms are allowed to comply using any technology, and could presumably choose to innovate rather than use an existing control technology, this is the exception rather than the rule because permits are easier to obtain when the technology used as a basis for the standard is employed. Thus, performance standards often act as de facto technology standards. Third, firms are reluctant to take high risks to meet environmental goals. These three factors combine to limit the incentives that standards have provided for firms to innovate. Standards are thus ranked weak on the characteristic of priding strong political incentives.

On the positive side, standards do serve as a stimulus to industry generated information, and there are new initiatives under way to provide greater flexibility and a multi-media focus. As a stimulus to industry generated informa-

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tion, current practice is much weaker than its potential. The time between initial recognition that there may be a need for a standard and the actual promulgation of standards generally provides a period of years during which all stakeholders explore options for managing a particular pollutant. Unfortunately, too often industry efforts are directed toward fighting stringent regulations, and thus the information generated is not directed toward innovative solutions. Standards are thus ranked moderate for industry generated information.

The initiatives in flexibility and multi-media regulation are relatively new. The flagship federal initiative is Project XL, which stands for 'Excellence in Leadership.' Under Project XL, industry and government agencies can petition for regulatory flexibility in exchange for producing an overall increase in environmental quality.[12] The EPA has also approached the question of multimedia and flexible regulation by supporting, on an experimental basis, regional and state-wide efforts for multi-media permitting and enforcement (Roy and Dillard, 1990; Buelow and Jacques, 1996). Because these experimental initiatives work within a regulatory framework that is neither flexible nor multi-media, at this point standard-based approaches are ranked 'weak but improving' for these two characteristics.

As a mechanism for creating the remaining two conditions – uncertainty reduction and lifecycle perspective – standard-based regulatory action in the U.S. is weak. Standard setting has often been reactive, and does not take a long-term view or provide for increasing reductions in emissions over-time. As with most generalities, there are exceptions to this, for example standards for energy efficiency. Thus far, a lifecycle perspective is beyond the purview of individual standards. This viewpoint would be brought into standards only to the extent that an industry and its supply chain were viewed simultaneously.

Standard-based approaches will remain with us to guarantee a baseline of public and ecosystem health and because they have some design and implementation advantages (Bacow, 1980; OTA, 1995). In this role, they will most often drive diffusion rather than innovation. Several reforms in design and implementation would make standards a greater force for innovation. However, the most often recommended prescription for regulatory reform, the use of performance rather than technology standards (Rothwell, 1992; Porter and van der Linde, 1995), is somewhat off-base. In a recent study, the U.S. Office of Technology Assessment could not find any current examples of the use of technology standards (OTA, 1995: p. 97). The real issue here is the extent to which performance standards act as de facto technology standards, as discussed above. Thus, the reform that is necessary is to strengthen efforts that are currently underway to make permitting of innovative technologies easier (Cooper, 1997) and to provide additional incentives for firms to innovate rather than choose the proven technology. The latter could include incentives for beyond compliance behavior, such as reduced monitoring and streamlined permitting; the development of multi-media standards;[13] flexible enforcement (Becker and Ashford, 1995; EPA, 1993); and 'rolling' standards that get increas-

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ingly stringent over time. In particular, 'rolling' standards would reduce uncertainty, sending a message to firms to consider innovative technologies that either go beyond current compliance or will allow for further improvements in the future without another round of major investment. Finally, firms could make different choices during the pre-promulgation phase, paying greater attention to how to innovate their way out of environmental regulatory oversight.

Market-based mechanisms

Market-based mechanisms have been posited as the key alternative to standard-based approaches.[14] They are advocated largely for the economic efficiency gains they can provide, some of which may be achieved by technological innovation. By providing an economic signal that makes each additional reduction in pollution profitable, market-based mechanisms can engage the attention of business managers, who may then direct company resources toward innovative ways of reducing pollution. If sufficiently costly, they can serve as a motivation for on-going efforts at emission reductions.

We have little actual practice with market-based mechanisms at the national level. The experience we do have is based on the combined use of standards and market mechanisms, in which standards are used for setting an environmental goal (e.g. levels of emission reductions) and marketable permit systems are used to implement the goal. Examples of this include CFC permits and the 1990 Clean Air Act (CAA) amendments sulfur traing program for reducing acid rain precursor emissions (Tietenberg, 1995; Burtraw, 1996; Jung, Krutilla et al., 1996). When used as an implementing mechanism, market-based mechanisms provide greater flexibility than standards. However, their ability to provide incentives to innovate remains linked to the level of environmental protection required by the performance standard. Thus, in the case of CFCs, under international treaty, we are obligated to implement a complete phase out, and this has led to considerable technological innovation in products and processes. In the case of sulfur under the CAA amendments, the innovation that has occurred is related more to the flexibility provided by the switch to performance standards than to the marketable permits (Burtraw, 1996). In sum, based on U.S. practice, the market-based mechanism (of tradable permits) scores quite similarly to the performance standards.

There are a variety of prescriptions for improving the design of marketable permit systems, and because of the flexibility they allow, with greater experience this implementation mechanism could be designed so that it stimulates greater trading and greater innovation, at least for some pollutants or industries (Burtraw, 1996; Hausker, 1992; Tietenberg, 1995). Alternative market mechanisms that provide direct economic incentives, such as pollution charges (i.e. taxes) and investment tax policy, if large enough, could provide a stronger stimulus for innovation. These tools differ from permits in that they use market approaches as a tool for setting policy goals as well as the implementation

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mechanism of choice. These mechanisms could be used in conjunction with standards, with the pollution charges or tax breaks acting as incentives for firms to go beyond compliance requirements.

Although taxes and tax policy have the potential to stimulate innovation, politically they have been a non-starter. The recent failure in the U.S. to pass a significant and comprehensive energy tax shows the difficulty in moving toward a system that taxes resources or pollution.[15] In the U.S., the states are taking the lead on 'green taxes' (Hoerner, 1995). Many of these taxes are revenue generators, to build funds for environmental clean-up or preservation. It is worth further investigation into whether these state taxes have stimulated technological innovation, as well as the role taxes have played in technological innovation in other OECD countries that have used taxes more aggressively as part of their environmental policy (OECD, 1995).

Information

Information based programs come in two varieties: (1) programs in which government provides information to industry and the public (e.g. technical assistance) and (2) programs where industry is asked to provide information to the government for public dissemination (e.g. 'right-to-know' legislation). The former type, where government provides information, can be used to promote technology diffusion, and as discussed in the next section, is a key component of the voluntary programs. The focus of this section is on the latter, industry providing information for public dissemination. This is a newer approach in environmental policy and potentially more effective from an innovation viewpoint.

The major federal program in this area, the Toxics Release Inventory (TRI), requires that industry annually provide data on its releases of 602 chemicals.[16] The original legislation included only 316 chemicals, and required manufacturing firms to supply data at the facility level on releases to all media (air, water, land) as well as on-site and off-site storage, treatment, and disposal. As part of the 1990 Pollution Prevention Act, the TRI was amended to include reporting for on- and off-site recycling and energy recovery, a production index so that changes in releases and transfers could be related to changes in production, and a requirement to report qualitatively on source reduction activities. For source reduction reporting, firms must report on the types of source reduction undertaken, but not the amount of chemical waste or emissions reduced through source reduction. The TRI was further amended in 1995, when 286 additional chemicals were added to the TRI list.

The driving force for this legislation was the community-right-to-know campaigns of the mid-1980s. In complying with this legislation, both firms and the public have developed greater knowledge of the sources, types and quantities of emissions. This knowledge has enabled firms to identify opportunities to reduce emissions while saving money and enabled the public to exert pressure

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on firms to reduce emissions. No company wants to be on the list of the 10 top emitters. With the 1990 and 1995 changes, the TRI provides more complete data on toxic releases and transfers, and thus may serve better the function of generating information within the firm that can stimulate pollution prevention.

Early results suggested that transfers and releases of TRI chemicals were declining, with total reported transfers and releases dropping by 35% from 1988 through 1992 (INFORM 1995). The more complete data required by the 1990 amendments, which included data on transfers to recycling and energy recovery, paints a somewhat different picture. Although total releases and disposal continued to steadily decrease, transfers increased enough so that the total TRI chemicals in waste increased by 6.5% from 1991 to 1994. More specifically, total releases and disposal decreased by 20.2%, while recycling, energy recovery and treatment increased by 17.9%, 13% and 9.9%, respectively (EPA, 1994).

It is difficult to normalize the TRI for the level of production, although such a normalization could provide a better understanding of trends in TRI chemicals. Using an approach based on the value of production by manufacturing sector (a rather crude categorization, but an approach that is feasible given available data), EPA analysis suggests that while total waste increased by 5% for the manufacturing sector from 1991–1994, waste per unit of economic output decreased by about 7% during this period.

From 1991–1994, about 1/3 of facilities reported at least one source reduction activity. Efforts to correlate waste reduction with reported source reduction activity have been contradictory. INFORM's assessment of 1991 and 1992 data suggest that facilities reporting source reduction had, on average, reductions in total waste generation. The EPA assessment of 1993 and 1994 data suggested a negative correlation between reported source reduction activity and the level of total wastes. Case studies support the conclusion that pollution prevention activity is taking place in some firms (EPA, 1994; EPA, 1995). However, based on the TRI data, it is difficult to develop quantitative measures of waste reduced through prevention, or to link this reported source reduction either to TRI or to technological innovation. In sum, these data indicate that some source reduction is taking place, but that progress toward a minimal waste society is quite slow. The good news is that releases and disposal are decreasing while the recycling and energy recovery are increasing at a faster rate than treatment. Nonetheless, emissions and disposal per unit of output will have to decrease at a much faster rate to reduce total production related waste.

With respect to the characteristics for stimulating technology innovation, TRI ranks moderate on industry generated information and incentives. Although TRI requires considerable information generation, there is inconsistency in reporting and frequent use of engineering estimates which may not reflect actual emissions. It ranks moderate on incentives because although the public release of data has created citizen pressure, the amount of source reduction is low, suggesting citizen pressure has been most successful in pushing for emission reductions through end-of-pipe technology and recycling. TRI ranks high for multimedia focus and flexibility, as it requires reporting on all discharge

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streams and firms can respond to this information in any manner they please. It has little or no effect on the reduction of uncertainty and lifecycle focus.

In terms of improving TRI as a force for innovation, suggestions include reporting on additional industries and chemicals, and requiring reporting on chemical use in addition to chemical waste. A few states have programs that require reporting on chemical use (Gottlieb, 1995, 143–149). Evaluation of these programs should inform the discussion about chemical use reporting. Efforts to improve the quality of data would also increase the effectiveness of TRI.

Voluntary programs

In its efforts to promote pollution prevention, the EPA has embarked on a series of voluntary programs. These programs function by providing technical information and public recognition to participants, and in return ask that participants make a commitment to a goal of pollution reduction or technological change that leads to pollution reduction (Stoughton, 1995). As of 1996, the EPA had 28 voluntary initiatives (EPA, 1996). The voluntary programs can be grouped into two basic types: those that specify goals for environmental improvement but no specific technology and those that are focused on the diffusion of specific technologies.

The best known example of the first type of voluntary program is the 33/50 program. The 33/50 program, which was started in 1990, asked corporations to reduce the releases and transfers of 17 toxic chemicals 33% by the year 1992, and 50% by 1995. One of the goals of the program was pollution prevention, so the EPA asked companies to consider source reduction as the preferred method for meeting their 33/50 commitments.[17]

The second group of programs are designed to increase the diffusion of technologies and practices that are 'win-win.' The best known example of this is the Energy Star program, although similar programs exist for water conservation and waste reduction. The Energy Star program, whose flagship project is Green Lights, asks companies to agree to undertake cost-effective energy efficiency measures, and to design energy efficiency features into products. In addition to lighting, the Energy Star family includes programs in office equipment, office buildings, residential buildings, computers, and transformers.

The following quote from a press release on the 33/50 program describes the attraction of voluntary approaches.

> 33/50 is an example of government reinvention at its best. No new regulations, no top heavy staffing or resource needs, no cumbersome 'adminstrivia' eating up time, patience and goodwill. Just a simple challenge with clear-cut goals.

Many of the voluntary programs can point to concrete achievements in pollution reduction. For the purposes of this analysis, the questions that need to be asked are: to what extent are these reductions driven by the voluntary programs

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rather than other factors, to what extent are the reductions achieved by pollution prevention rather than pollution control, and is the pollution prevention based on innovation or diffusion?

The 33/50 program exceeded its 1992 goal, with firms achieving 40% reduction in releases and transfers (EPA, 1994). The 1995 goal was met one year early; participating firms achieved 55% reductions by 1994.[18] The 17 chemicals that were included in the 33/50 Program shared the following four attributes: they posed a serious health risk, they were large volume chemicals with substantial releases, their releases could be reduced through pollution prevention, and they were regulated under the 1990 CAA amendments (INFORM 1995). It is thus unclear to what extent the reductions were driven by the 33/50 program or by these other factors.

Because of the 2-year delay in releasing data, currently there is a comprehensive statistical assessment of only the first two years of the program. An interim assessment based on 1991 and 1992 data concluded that reductions in the 33/50 chemicals were the same for participating and non-participating companies (INFORM 1995). However, EPA analysis of 1993 data suggests that this has changed, with participating companies achieving significantly higher rates of reduction in 1993 (6th annual progress review). Data to evaluate whether this reduction is being achieved through pollution prevention is sparse, as companies are not required to report amounts achieved through source reduction on the TRI, but only whether they engage in source reduction. As mentioned in the discussion of the TRI, there is evidence that some firms are engaging in source reduction.

The Energy Star Programs have resulted in significant energy savings, although they have captured only a fraction of the total potential for energy efficiency gains in equipment and buildings. Savings estimates are available for some of the more established programs. As of 1996, Green Lights participants have saved $172 million annually, compared with EPA's estimate of a $16 billion potential annual savings from lighting upgrades (Eisele, 1996).[19] The Energy Star Office Equipment program estimates that in 1995, 30% of computers and 80% of laser printers sold carried the Energy Star seal, indicating that they 'power down' when not in use.

All the voluntary programs stimulate firms to generate information, although those that are not technology-specific are more likely to result in the development of information directed toward innovation (as contrasted to diffusion). For programs like the 33/50 program, meeting the agreed upon goal depends almost completely on the industry developing or seeking out methods for emission reductions. In contrast, in Green Lights the government disseminates information about best technological practices. But even in this case, the firm must audit its own activities, and thus generate the information needed to assess whether the proposed solutions are cost-effective for its buildings and operating conditions. Although this is most likely to result in diffusion, by creating a set of companies that are educated on the potential for win-win investments in retrofitting or purchase decisions, these programs can result in

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firms identifying opportunities for innovation, or demonstrate a demand to suppliers, which would then be motivated to create new technological solutions. Given this range of approaches in the voluntary programs, I rank them moderate for industry generated information.

The direct incentive that voluntary programs can provide is publicity about a company's pro-environment activities.[20] This can provide companies with a legitimized response to public pressure for environmental improvement.[21] However, the public recognition available from these programs for good behavior is weak, particularly in comparison to the negative publicity that TRI can generate.[22]

The voluntary programs do provide some flexibility, uncertainty reduction and a multimedia perspective. Flexibility of response exists because different firms may choose different ways of meeting goals, although this is not particularly relevant in cases where a specific technology is being promoted, such as green lights. Some reduction in long-term uncertainty is created through the goals that are established by voluntary programs, which create a beyond-compliance benchmark for best-practice. To the extent that firms meet this benchmark, and in the process make improvements in technology, it is easier to incorporate these technological changes into future standards. As regards a multi-media perspective, because the voluntary programs are often targeted at pollution prevention, many of them impact multiple emission streams. Finally, in terms of lifecycle perspective, these programs tend to target actions in a particular part of lifecycle, thus not promoting a lifecycle approach.

From the standpoint of promoting innovation, voluntary programs could be improved by identifying longer-term and more challenging goals. For example, Green Lights participants agree to undertake actions that have a 20 percent IRR on a facility-wide basis. This essentially means that only the clear win-win actions will be taken, and thus the motivation for innovation is minimized. As another example, if firms could meet 50% reductions in the 33/50 chemicals in less than 5 years, what kind of actions would they have taken toward a goal of 80% reductions in 10 years? A longer term vision of this sort may be able to stimulate greater innovative responses, as the cost and capability of end-of-pipe controls would look less attractive. The downside of this more challenging approach is that longer-term goals for greater emission reductions could reduce the attractiveness of participation.

Industry councils

A very recent innovation in U.S. environmental management is the Common Sense Initiative (CSI). The CSI is organized by industry sector, to facilitate the consideration of the full range of environmental issues for a particular industry rather than the more traditional focus on single pollutants or single media. The Clinton Administration's initiative in reinventing government was the catalyst for the CSI, which hopes to create 'cleaner, cheaper and smarter' solutions for

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the environment. The industries were selected based on the level of interest within the industry and EPA's previous experience working with these industries on innovative regulatory projects. The CSI industries are: automobiles, computers and electronics, iron and steel, metal finishing, petroleum refining, and printing. These industries account for 11% of the U.S. GNP, and 12.4% of the toxic releases reported by all American industry.[23]

The CSI is run by a council that includes representatives from industry, environmental groups, environmental justice concerns and state regulatory agencies. The real work of the CSI takes place in the industry subcommittees, whose membership also represents all the relevant industry, citizen, and governmental stakeholders. The decision process of these subcommittees is by consensus. The charge to the subcommittees is quite broad. They were advised to make recommendations and offer pilot projects in the following categories: regulatory improvement, pollution prevention, reporting requirements, compliance, permitting and environmental technology. Thus, the industry subcommittees can focus on both the short-term goal of streamlining compliance with current regulations (e.g. changes in permitting and reporting) and longer term goals of creating alternative industry-wide responses that could result in pollution prevention that goes further than current regulation.

In its nascent current practice, CSI seems to emphasize the first of these goals, alternative compliance strategies, more than the latter, pollution prevention. An analysis of the 37 CSI projects that had been proposed as of June 1996, shows that 26 (70%) focus on regulatory reform. About 25% of these regulatory reform projects also have a pollution prevention or multimedia focus. Of the remaining 11 projects, 7 focus on pollution prevention, three on innovative technology and one on strategic planning.[24]

Although CSI is only in its early phases, it is possible to speculate about how CSI will rank on the six design characteristics based on the initial proposals. CSI could result in substantial generation of information by industries, because it focuses attention on the full range of environmental issues facing an industry rather than looking at environmental management through the lens of specific media-based regulations. Furthermore, projects aimed at redesigning reporting requirements have the potential to focus information generation in a way that helps firms identify opportunities for pollution prevention. At least two of the five projects on reporting reform are focused on changing reporting requirements so that the information generated is truly useful to the industry and other stakeholders in their efforts to reduce pollution. Another area where the industry councils have strong potential is flexibility. Much of the regulatory reform is aimed at allowing flexibility to choose innovative technologies and innovative ways of reducing the overall environmental impact of an industry rather than specific waste streams. Early indications are that the potential of CSI may not be captured (Todd, 1997). As of June 1997, none of the initial proposed projects have been implemented. The sub-committees were not empowered to move forward and in some cases did not develop effective dialogues between the many stakeholders. Many of the stakeholders have lost interest, believing that

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this program will not achieve results. In sum, based on strong potential but difficult early implementation, I give this program perhaps too much benefit of the doubt and rank CSI as medium for information generation, flexibility and a multi-media approach.

The CSI does not provide strong economic or political incentives for investment in innovation. Although pollution prevention may result from some of the regulatory reforms, it will be because of information generated and not higher compliance requirements. Likewise, the multi-stakeholder approach of these councils will provide an avenue for expressing public pressure, although the councils themselves are not likely to create additional public pressure.

In theory, these voluntary councils have the ability to consider longer-term directions for moving toward much lower waste industries, as well as life-cycle issues. In practice, this has not been a major focus of the councils. The first round of projects included only 1 on lifecycle management, 1 on zero discharge, and 2 on beyond compliance.

While there is clearly a need for regulatory reform, and some of the reforms that are being pursued in reporting and permitting will result in greater industry generated information and flexibility, these voluntary councils could become a more effective force for 'green' innovation *if* they took on the question of how to move their industry toward a minimal emissions industry. This would mean setting longer-term goals that included more attention to lifecycle approaches. It would also mean investing time and money in the technological, organizational, and policy work that must be done to move from the current environmental impacts to minimal environmental impacts.

New initiatives overseas: Product stewardship

Product stewardship, often referred to as product take-back, is an approach that places the responsibility for the disposal of products with producers and/or distributors and retailers rather than with the end-user. By moving the responsibility for disposal upstream from the consumer, this approach creates incentives for manufacturers to reduce the costs of disposal by reducing the throwaway component of a product and increasing its reusability and recyclability. The most developed example of a policy based on product stewardship is the Ordinance on the Avoidance of Packaging Waste (Verpackungsverordung) which was promulgated by the Federal Republic of Germany in 1991. There is talk of expanding this approach to include durable goods such as automobiles, and household appliances such as washers and refrigerators. Product stewardship is also being pursued voluntarily by some companies as a more environmentally sound and possibly competitively advantageous business strategy (Smart, 1992; Sekutowski, 1994: p. 128–131).

The German Packaging Ordinance divides packaging into three categories: transport, secondary and primary (Biocycle, Ryan). It requires that transport packaging be reused or recycled outside of the municipal waste stream. Re-

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tailers were required to provide collection services for secondary packaging and to pay for its recycling or disposal. Primary packaging, which accounted for 2/3 of the waste stream by weight, created the largest challenge for recycling, reuse, and reduction. The ordinance set up recycling goals for primary packaging and provided two options for meeting these goals. Either retailers would have to charge a deposit for many types of containers and take-back all primary packaging, which would then be returned via distributors to manufacturers who would be responsible for recycling or re-use; or industry could develop its own system of collection and recycling. Industry chose the latter route as a way to avoid manufacturer-by-manufacturer take-back and developed the Duales System Deutschland (DSD), also known as the 'Green Dot System.' The recycling goals for 1993 ranged from a low of 6 percent for composites to a high of 42% for glass. The goals for 1995 were 72% for glass, tin, and aluminum, and 64% for plastic, paper and composites (Rousso and Shah, 1994).

The DSD has set up a collection infrastructure of drop-off and curbside collection, coordinating its efforts with existing municipal systems to avoid duplication of efforts. The DSD sells licenses to manufacturers, who are then authorized to put a green dot on their packaging, signaling that it can be collected by the DSD system. In order to qualify for the Green Dot, a manufacturer must submit their packaging to the DSD, which evaluates whether it can be recycled before granting the certification. Although not initially the case, currently licensing fees are set to reflect the cost of recycling specific packaging materials.

Although the implementation of the DSD has not been without problems, as will be discussed below, it has resulted in some clear successes in waste reduction and material substitution. New, reusable systems have been developed for transport packaging. Much of the secondary packaging has been eliminated, with estimates ranging from 40 to 80% reduction (BioCycle, 1994: p. 62). For primary packaging, there has been both a reduction in the total amount of packaging and a substitution of paper and cardboard for the more difficult to recycle plastics (Ryan, 1993). By 1993, total packaging waste had declined by 8% (BioCycle, 1994: p. 61) and there was a 15% reduction in overall household waste. The DSD collected 57% of sales packaging, and 85% of the packaging collected was recycled. The 1993 goals for recycling have been met or exceeded for glass, paper, plastics, iron and composites. Aluminum is the only case where the 1993 target was not met. However, for plastics, iron, and composites, the 1993 recycled rate was far below the 1995 target. Thus, the ability to meet the considerably more ambitious 1995 targets may be difficult (Schmitt-Tegge, 1990).[25]

Comparing this to the criteria for promoting technological innovation, this approach scores strong on most of the criteria. By forcing industry to take responsibility for packaging at the end-of-life, it has stimulated industry to develop information on both how to reduce packaging, how to use more easily recycled packaging, and how to recycle packaging that is currently not recycled. This ordinance scores strongly on incentives, as it has created economic, com-

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pliance and public pressure for reductions in waste and recycling.[26] The ordinance allowed considerable flexibility, as industry was permitted to develop its own system for meeting the ordinances goals, with the stipulation that the government would impose a system of fees if industry did not create an effective private sector system. Product stewardship is a lifecycle approach, although it has limitations, in that it considers only certain aspects of lifecycle, based on impacts related to material use and disposal, but not to production or use. Through its lifecycle consideration, product stewardship reduces impacts in many media, although it is not a panacea in this respect, as it still results in a trade-off between different environmental impacts without establishing any environmental criteria for making these decisions. For example, due to the difficulty of recycling plastics, the DSD charges a higher licensing fee for plastic containers. This has resulted in an increase in the use of glass, which in turn has resulted in greater energy use in transport, bringing with it an increase in air pollution impacts.

While this article is focusing on environmental policy as a driver of technological innovation, policy mechanisms must meet other criteria as well.[27] One such criteria, cost effectiveness is a subject of debate in relationship to the German Packaging Ordinance (Schmitt-Tegge, 1990). Another concern has been the impact of German packaging waste on international recycling markets. As a result of greater successes in collection than in recycling, Germany has become the largest exporter of wastes in Europe. This was not the intent of the legislation, and certainly would make this approach untenable on a more international scale. Thus, full success will require further innovation, particularly in the development of processes for recycling plastics and in the development of products that use higher levels of recycled inputs.

In terms of the design of future product stewardship legislation, the German experience thus far provides several insights (BioCycle, 1994; Burt and Dillon, 1994; Rousso and Shah, 1994). First, it is important that fee structures reflect the costs of recycling in order that proper signals are sent and that the system remains financially viable. Secondly, both supply and demand are necessary, and it is easier to set up collection systems than to create demand for the collected goods. Thus, greater thought needs to be put into policy mechanisms, such as R&D, procurement policy and tax policy, that promote the development of an infrastructure for processing and using the recycled materials.

Conclusion: Future directions for policy

This article starts with the premise that achieving a minimal waste society will require a wholesale reshaping of industrial society, which in turn will depend on radical technological innovation. Through its analysis of current U.S. policy, it makes clear that the goal of a minimal waste society will also require substantial policy innovation. This assessment began by discussing the relative ineffectiveness of standards, as currently practiced in the U.S., in promoting pollution

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prevention innovations. It then proceeded to examine five alternatives to the standard-based policy, four implemented in the U.S. and one in Germany. The greatest strength of the U.S. policy reforms has been in stimulating industry generated information and allowing for flexible responses. Although the alternatives satisfy more of the conditions for stimulating innovation, they show across the board weaknesses in several areas, including providing economic and political incentives, lowering long-term uncertainties, and taking into account lifecycle and multimedia concerns.

Despite these weaknesses, the usefulness of the recent policy innovations should not be underestimated, as they are likely to be an effective means for capturing the win-win potential of technological change for the environment, i.e. the potential to improve both environmental and economic performance simultaneously. More specifically, because of these reforms, firms are likely to develop the necessary information base and to have a freedom of action that will both motivate and make it possible for firms to engage in technological change for the environment when it has clear and relatively short-term profit potential.

However, in many cases there is considerable uncertainty about the potential for profits in pollution prevention. For many industries, there is no currently commercialized or near-commercial technology that can profitably move that industry strongly toward minimal wastes. But it is also likely that in these situations, there are potential innovations that in the longer term could result in gains for the environment and possibly for economic efficiency as well. Private sector investments in 'green' innovation in these instances are quite risky. To press innovation in these situations will undoubtedly require some combination of reduction in long-term uncertainty and stronger incentives. This could take the form of longer range goals for continued environmental improvement, thus sending a message to firms to take on technological change for the environment as a serious part of their business strategy. Furthermore, in these instances the government may have a role to play in both supply push and demand pull.

The lack of a lifecycle approach in these reform efforts represents a severe limitation. However, this conclusion is in part an artifact of this analysis; it is difficult for a single policy mechanisms to address environmental impacts throughout the lifecycle. We will likely need to consider lifecycle issues through more coordinated overall planning, with the goal that single mechanisms will not move opposite to lifecycle goals.

In practice, none of the U.S. alternative approaches satisfy the conditions needed for stimulating innovation as well as the German implementation of product stewardship. This leads to two important points. First, innovation is only one criteria for environmental policy, and it must be added to rather than replace the more traditional criteria of effectiveness, efficiency and equity. There is debate about the cost-effectiveness of the German product take-back. While this article does not evaluate the validity of that controversy, it is important to mention within this context that innovation at the expense of other cherished

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values is not a viable path to a minimal waste society. The second point is that many of these policy options could be redesigned to satisfy more of the criteria for technology innovation. There is little reason to suggest, a priori, that any single policy mechanism is better for technology innovation. Successful policy for promoting innovation is likely to be multifaceted, designed to respond to the unique characteristics of different industries and environmental challenges, as well as the perspectives and interests of a range of stakeholders.

Acknowledgements

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Notes

1. The field of inquiry examining the possibility of a closed-loop industrial society has alternatively been called industrial metabolism and industrial ecology. See Ayres, R. U. (1989). Industrial Metabolism. *Technology and Environment*. J. H. Ausubel and H. E. Sladovich. Washington, DC, National Academy Press: 23–49 and Frosch, R. (1995). 'Industrial ecology: Adapting technology for a sustainable world,' *Environment* 37 (10): 16–24, 34–37.
2. As generally used, the definitional distinctions are as follows. Pollution prevention is often equated only with in plant process changes. Eco-efficiency and resource productivity are equated with product and process changes within a firm. Industrial ecology suggests a larger system-wide perspective on reducing wastes. Note that technological innovation will not in itself lead to sustainability. Changes in values, institutions, and behavior will also be necessary to reach sustainability goals.
3. See Branscomb, L. M., ed. (1993). *Empowering Technology: Implementing a U.S. Strategy*. Cambridge, MA, The MIT Press, p. 13–18, for discussion of differences between 'megaproject' technology and civilian technology.
4. Several analysts have identified the existence of a clear objective and public consensus as an important factor in successful federal technology programs. See Rothwell, R. and W. Zegveld (1981). *Industrial Innovation and Public Policy: Preparing for the 1980s and 1990s*. Westport, CT, Greenwood Press, Dalpé, R. (1994). 'Effects of government procurement on industrial innovation,' *Technology in Society* 16 (1): 65–83, and Levin, M. H. (1990). 'Implementing pollution prevention: Incentives and irrationalities,' *Air & Waste Management Association* 40 (9): 1227–1231.
5. This article focuses on the role of federal government policies in the creation of private sector demand. Because of the focus on private sector demand it does not consider federal procurement policy. This is a policy mechanism that deserves further investigation. Some analysts have noted the importance of niche markets in the early development of new technologies, Schot, J. (1992). 'Constructive technology assessment and technology dynamics: the case of clean technologies,' *Science, Technology and Human Values* 17: 36–56, Rip. A. (1995). 'Introduction of new technology: Making use of recent insights from sociology and economics of technology,' *Technology Analysis and Strategic Management* 7 (4): 417–431). Despite the fact that the federal government is not in a monopsony or oligopsony position with respect to most technologies that are important for pollution prevention, it may be a large enough consumer to help the technology through the initial phases of commercialization.
6. Some or all of these characteristics have been identified by Ashford, N. (1993). Understanding

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technological response of industrial firms to environmental problems: Implications for government policy. *Environmental Strategies for Industry*. K. Fischer and J. Schot. Washington, DC, Island Press, Porter, M. and C. van der Linde (1995). 'Toward a new conception of the environment-competitiveness relationship,' *Journal of Economic Perspectives* 9 (4): 97–118, Hill, C.T. and J. Utterback (1979). Environmental health and safety regulation and technological innovation. *Technological Innovation for a Dynamic Economy*. C.T. Hill and J. Utterback. New York, Pergamon Press: 200–204.

7. Rothwell, R. (1992). 'Industrial innovation and government environmental regulations: Some lessons from the past,' *Technovation* 12 (7): 447–458.
8. Theory on technological innovation suggests that industry characteristics will be important determinants of firm technological strategies, thus we may expect different policy mechanisms and different characteristics to be more crucial in specific industries. See Abernathy, W. J. and J. Utterback (1978). 'Patterns of industrial innovation,' *Technology Review* 80: 40–47; Pavitt, K. (1984). 'Sectoral patterns of technical change: Towards a taxonomy and a theory,' *Research Policy* 13 (6): 343–373; Ashford, N. A. (1994). An innovation-based strategy for the environment. *Worst Things First: The Debate Over Risk-based National Environmental Priorities*. A. Finkel and D. Golding. Washington, DC, Resources for the Future; Ashford, N. A., C. Ayers, et al. (1985). 'Using regulation to change the market for innovation,' *The Harvard Environmental Law Review* 9 (2): 419–466; Ashford, N. A. and C. R. Heaton (1983). 'Regulation and technological innovation in the chemical industry,' *Law and Contemporary Problems* 46 (3): 109–157.
9. The role of incentives has been captured in previous scholarship by the identification of stringency as an important element of regulatory design for the environment (Ashford, N. A. (1994). An innovation-based strategy for the environment. *Worst Things First: The Debate over Risk-based National Environmental Priorities*. A. Finkel and D. Golding. Washington, DC, Resources for the future, Ashford, N. A., C. Ayers, et al. (1985). 'Using regulation to change the market for innovation,' *The Harvard Environmental Law Review* 9 (2): 419–466, Ashford, N. A. and G. R. Heaton (1983). 'Regulation and technological innovation in the chemical industry,' *Law and Contemporary Problems* 46 (3): 109–157.) and by discussions of the preferability of economic instruments Milliman, S. R. and R. Prince (1989). 'Firm incentives to promote technological change in pollution control,' *Journal of Environmental Economics and Management* 17: 247–265 and Jung, C., K. Krutilla, et al. (1996). 'Incentives for advanced pollution abatement technology at the industry level: An evaluation of policy alternatives,' *Journal of Environmental Economics and Management* 30: 95–111.
10. Newell, R. G., A. B. Jaffe, et al. (1996). Environmental policy and technological change: The effect of economic incentives and direct regulation on energy-saving innovation. Cambridge, MA, Kennedy School of Government, Harvard University, find that prices, standards and labeling all had a positive impact on innovation for three energy saving consumer products.
11. Interests in alternatives is also based on the critique that standards-based regulation is economically inefficient, as well as the desire by some for less stringent regulation.
12. A good overview text on U.S. environmental policy is Portney, P. R., ed. (1990). *Public Policies for Environmental Protection*. Washington, DC, Resources for the Future. A comprehensive review of standards and other policy tools is OTA (1995). *Environmental Policy Tools*. Washington, DC, U.S. Government Printing Office.
13. For information on Project XL, see http://www.epa.gov/project XL.
14. See for example the proposed rulemaking for the pulp and paper industry.
15. Project 88, 1988, 1991.
16. In 1993, the U.S. Congress approved a 4.3 cent/gallon tax on gasoline, by a 51–50 vote in the Senate. In the summer of 1996, there was discussion of repealing even this modest tax.
17. The TRI was established under Community Right to Know Act of 1986. See INFORM 1995, 1994 toxics release inventory public data release. http:www.epa.gov/opptintr/tri/+94cntnt.ntm.
18. A variety of documents on 33/50 can be accessed through www:http://es.inel.gov/partners/3350.
19. EPA (1995). EPA's 33/50 program company profile reduction highlights, volume II. Washington, DC, Environmental protection agency. 6th progress report shows 46% reduction by 1993.

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20. Also see 'U.S. green lights program: Pollution prevention at a profit,' http://www.epa.gov/docs/GCDOAR/overview.html.
21. Arora and Cason's assessment suggests that this is a key motivation for firm participation.
22. Stoughton, M. D. (1995). 'An evaluation of voluntary programs as public policies for environmental protection,' *Civil and Environmental Engineering*. Cambridge, MA, Massachusetts Institute of Technology.
23. The Netherlands has undertaken this approach much earlier. Wallace, D. (1995). *Environmental Policy and Industrial Innovation: Strategies in Europe, the U.S. and Japan*. London, Earthscan Publications Ltd., 43–62.
24. 'The common sense initiative' from: http://www.epa.gov/docs/CSI/CSI/background/Factshee.txt.html.
25. Overview of common sense initiative projects, June 1996. http:/www.epa.gov/commonsense/3table.htm.
26. Data for 1995 was not available as of this writing. The article in Biocycle states that the 1995 deadlines have been moved forward to 1998 to allow for further development of the recycling infrastructure. Other articles written during the same period do not note this.
27. Some environmentalists objected to the provision allowing manufactures to form a collective system, suggesting that manufacturers would have a stronger incentive to reduce, reuse and recycle if they were each responsible for their own wastes. Three of Germany's 16 states voted against the ordinance because of this provision. Ryan (1993). 'Packaging a revolution,' *World Watch* (September/Octover): 28–34, 31).
28. OTA 1995 made an analysis of the relative effectiveness of alternative policy mechanisms for meeting different policy goals.

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