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TECHNOLOGY AND ENVIRONMENT: TOWARDS POLICY INTEGRATION

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FOREWORD

This document contains four papers which discuss government policies and programmes in OECD Member countries that could promote research and technology development to achieve sustainable development objectives. At issue is the better integration of technology policy and environmental policy needed to enhance innovation to improve environmental performance at the same time as contributing to sustainable economic growth and job creation. This will first require adapting environmental policies and combining regulatory, economic and other instruments to promote more environmental innovation. On the technology policy side, it demands evaluation of and improvements to OECD schemes to direct public/private research partnerships, technology diffusion, and technology foresight towards environmental and sustainable development goals. The papers in this document discuss features of these programmes which underline the role governments can play to better use science and technology for improving both economic and environmental performance.

These papers contribute to the on-going OECD horizontal programme on sustainable development. They are part of the work of the OECD Committee for Scientific and Technological Policy (CSTP) and its Working Group on Innovation and Technology Policy, which has discussed these papers. The work has also been co-ordinated with the OECD Environment Directorate. The studies have been prepared with the assistance of consultants Yukiko Fukasaku (Paris, France), George Heaton (Worcester, MA), William Westermeyer (Geneva, Switzerland) and Kirsten Oldenburg (Washington, D.C.).

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ENVIRONMENTAL POLICIES: TECHNOLOGY EFFECTS

SUMMARY

New technology is key to achieving sustainable development, but the environment/technology nexus remains poorly understood. Moreover, there has been little interaction between the realms of technology policy and environmental policy in most OECD capitals. This paper proposes a preliminary analytical framework for understanding the effects of environmental policies on technology development and diffusion and innovation in industry.

Environmental policy instruments differ in their effects on innovation. *Product standards* tend to prompt incremental innovation or modifications at the margin. *Product bans* can stimulate radical innovation in the form of replacements, but also entail disruptions and costs. *Performance standards* for industrial processes are technically flexible, while *technology specifications* tend to stifle innovation. *Economic instruments*, such as pollution charges and tradable permits, have more dynamic potential to stimulate innovation but have not always been set at sufficiently high levels in the case of the former or used extensively in the case of the latter. Nor have *voluntary agreements* brought much pressure for technological change thus far, although newer forms of environmental compacts with industry may hold more promise. Also valuable are approaches such as extended producer responsibility, information disclosure and environmental management systems, which can encourage the complete redesign of products and processes.

Certain policy reforms could promote more environmental innovation. In general, economic instruments should be used more frequently as substitutes for – and complements to – traditional forms of regulation. Moreover, changes in implementation as well as new approaches could substantially improve the regulatory framework for environmental innovation. The ways regulations are implemented and enforced have a strong influence on industry programmes to develop technologies to comply with new standards. Systems for early warning and timed introduction of new policies can reduce regulatory uncertainty for industry. Expedited government review procedures and verification and certification schemes can speed market introduction of new technologies. Shifting away from technology specifications towards end results can increase the flexibility for industry in achieving compliance. This will require an improved merger of environmental policy and technology policy and better co-ordination among environmental and technology agencies.

INTRODUCTION

Environmental policy in OECD Member countries has not generally focused on the positive connection between environmental improvement and technological innovation. While historical experience has varied from country to country, the early environmental movement, particularly in parts of Europe and the United States, often preoccupied itself with the adverse impacts of technology. Its policy legacy continues to emphasize governmental regulatory structures that tend to impose controls on the direction and character of industrial technology development.

Whatever the legacy, a set of new conditions in the relationship between the environment and technology appears to have emerged over the last few years. Environmentalism, long on the periphery, is now mainstream to the education of technology's architects: engineers and managers. Environmental values and modes of analysis have gained wide acceptance in the technology strategies of leading firms, and a global industry devoted to the production of environmental goods and services has been built (OECD, 1996). Environmental science and technology occupy a small but growing place in the public R&D portfolios of virtually all OECD Members. It may even be argued that the trajectories of today's technological revolutions – information systems, miniaturisation, biotechnology – are inherently less environmentally exploitive than those of the past.

If these trends suggest a new potential synergy between environmental goals and the direction of technological innovation, there is nevertheless much to be done to capitalise upon it. This is particularly true in the arena of environmental policy. This review of environmental policy and technological innovation is focused on the prospects for policy change to stimulate innovation, starting with a proposed framework for understanding the various factors that condition the relationship between environmental policy and technological change.

With regard to relevant concepts, *technological innovation* is routinely defined as the first use of a new product, process or system in a commercial context. A responsive commercial and social phenomenon, technological innovation occurs overwhelmingly in private firms in reaction to external signals. It is distinguished from *invention* – a new technical idea – and *science* – the search for knowledge. Radical and incremental innovations represent different degrees of change, the latter denoting smaller improvements along a given trajectory, and the former, major departures from the technical status quo. *Technology diffusion* succeeds innovation, as subsequent users adopt, often with adaptations, the technology pioneered elsewhere.

There is substantial theoretical and academic literature describing the process of technological innovation and postulating a variety of models to explain it. While little of this work pays public policy factors much attention, the depictions in these models of what conditions and motivates innovation are nevertheless highly relevant to public policy.

Perhaps the earliest, simplest scheme is a sequential and science-based model. In this construct, technological innovation is the outgrowth of scientific discovery, spawned by a sequence proceeding from research to development to commercialisation. Although these postulates are certainly over-narrow, assuming as they do that science must proceed technology, and ignoring the social and economic motivations for technological change, the idea that a scientific infrastructure and systematic research undergird technology development has long been one of the mainstays of public policy across all countries. Its continuing persuasiveness can be seen, for example, in the advocacy for increases in environmental basic research, ubiquitous throughout OECD Member countries, as the source of solutions to environmental problems.

Other models are more rooted in the changing characteristics of different industrial segments and technologies (Utterback, 1994). This evolutionary model postulates a predictable pattern of innovation over time, as the particular technology and its industrial context move from a "fluid" state, characterised by rapid change in product concepts and industrial structure, to a "rigid" state, often based on high-volume production and a small number of entrenched firms. From a public policy standpoint, the importance of the evolutionary model is that it predicts the kind of responses that will arise to external influences – environmental regulations or others – based on the changing character of the industry and technology affected.

Another approach has focused on the set of conditions, both internal and external to firms, that prompt innovation and entrepreneurship in a type of dynamic model (Roberts, 1991). Recognising the inevitably disruptive influence of innovation, this model is absorbed with the factors – organisational, economic, social – that produce a "dynamic" environment in which changes to the status quo can flourish. Small firms, new firms and new entrants to established businesses are thus seen as particularly fertile sources of innovation. Public policies – whether environmental or others – are seen in this formulation as either a spur to innovation, to the extent that they challenge the status quo, or a deterrent, to the extent that they impede entrepreneurship.

Most recently, considerable attention has been devoted to the idea of an innovation system model – comprised of many interacting parts (OECD, 1999*b*). Some are even calling this an "*innovation ecosystem*". The innovators thought to be most successful in this context are those who most adroitly mine the diverse sources of expertise with respect to any problem – universities, government laboratories, competitors, other countries – and harness their efforts in co-operative enterprises. Current experiments in environmental policy can be traced to this mindset to the extent that they focus on public-private partnerships and common solutions to industry-wide problems.

FRAMEWORK FOR ANALYSIS

Using these models of the innovation process as background, a framework of the relationship between environmental policy and technological change is presented schematically in **Figure 1**. The framework describes the interaction of private firms and public policy in seeking technological solutions to environmental problems. It consists of three components and the signs linking the three components in a formula suggest that the character of technological responses to environmental policy will be determined by both the initial contextual situation and the character of the public policy stimulus, in approximately equal measure. The main elements of this framework are:

1) *A set of pre-existing technical, organisational and economic variables facing developers and users of technology.*
2) *The stimulus of environmental policy, which can take a variety of different forms.*
3) *A range of possible technological and other responses.*

Figure 1. Framework for analysing technological responses to environmental policy

Contextual variables **+**	***Public policy instruments***		**→** ***Technological response***	
	Mechanism	*Character*	*Degree*	*Origin*
• Environmental problem	• Regulations/ standards	• Time frame	• No innovation	• Polluting sector/firm
• Technological context	• Economic instruments	• Stringency	• Radical innovation	• New firm/ entrant
• Industry structure	• Voluntary agreements	• Flexibility	• Incremental innovation	• Environment industry
• Firm characteristics	• Producer responsibility	• Cost	• Diffusion of technology	• Other
• Market and social factors; prices	• Information disclosure.	• Uncertainty	• Continuing innovation	

Source: Heaton, 1997.

The contextual variables show the set of boundary conditions which limit the technological responses to environmental policy, as well as the nature of the innovative climate from which they will spring. It is of course apparent that the nature of the environmental problem at hand – air pollution, water pollution, waste, toxic substances, hazardous products, etc. – conditions the nature of the solution. The more subtle point, however, is that different ways of framing what the environmental goal consists of can dramatically affect the kinds of technologies that arise in response. For example, the vast majority of environmental regulations speak in terms of pollution control for a particular environmental medium at a certain level - which has, for the most part, prompted the installation of "end-of-pipe" clean-up technology. Were environmental goals more frequently conceptualised in terms of overall pollution prevention and long-term minimisation of resource use across media, major changes in the design of technology would be a much more likely response.

The variables pertaining to the nature of the technology, industry structure and firm character all need to be seen with reference to the models of technological innovation outlined above. For example, whether the technological system in which an environmental problem arises is fluid and flexible or mature and rigid will determine its propensity to change, including the speed, scope and innovative character of the resulting technologies. Similarly, if the industry struggling with environmental problems consists of a few large firms, the likelihood of diverse, radical solutions will be less than in a highly entrepreneurial business environment. Even within a single industrial context, the innovative potential of individual firms will vary widely, along with the value set of the firm, which may be either consonant with or antagonistic to public policy trends. Lastly, it bears repeating that technological innovation is highly responsive to social and market factors, which often precede or supersede public policy. Getting the prices right for resource inputs and other technological variables is the most effective way to stimulate long-term environmental innovation (OECD, 1999*a*).

The public policy stimulus of concern in the framework is the body of laws, regulations and institutions whose purpose is to improve environmental quality. Such policies cover a wide – and growing – range of topics, including industrial pollution, transportation, energy and resource use, land development, consumer products, agriculture, etc. While the analysis here will fix on these traditionally "environmental" policies, it should be noted that mounting public concern has inserted environmental elements into many other policy arenas – technology policy notably – and that the policy stimulus has therefore become more complicated and diverse than ever before.

Two elements of the policy stimulus need to be distinguished: the policy mechanism employed and the character of the signal the responding entities perceive. A detailed consideration of how policy instruments affect technology is presented in this paper. While less frequently analysed, the character of the signal the user or developer of technology receives from public policy is equally important. For example, the many pollution control regulations based on the "best available technology" currently employed by leading firms in an industry present no stimulus at all to innovation (especially by those firms already using it), but will promote diffusion of technology to industry laggards. Similarly, short time frames for compliance often force firms to adopt the least innovative, but least risky, technologies. The institutional nature of the policy development and implementation process is also important: conflictual crime/punishment approaches will yield different innovation responses than more consensual arrangements. The degree of uncertainty about government policy, and fear that innovation will lead to ever more stringent standards, are also important factors (OECD, 1985). The dynamic of these and other conditioning factors to the use of environmental policy instruments is analysed below.

Technological responses to environmental policy also appear as two subsets: the degree of change and the locus of the technology's origin. In polar cases, environmental policy may produce no change at all – for example, among firms already in compliance or those who chose not to comply – or at the other extreme, radically redesigned technologies. In less extreme cases, the response is likely to be incremental changes to an established technical paradigm, or simple diffusion of proven approaches to new contexts. It is also important to consider whether the need for innovation to satisfy environmental policy is continuing (like most other performance criteria) or whether it may be satisfied by a single technological modification.

The locus of technological change in the environmental field has broadened considerably over time, making this an important element of the framework. Beyond the continuing role of the regulated sector, the development of a global environmental goods and services industry over the last two decades has established an entirely new sector as a source of environmental technologies (OECD, 1996). Particularly where radically new solutions to environmental problems would challenge the status quo in an industry, new entrants (or potential new entrants), who have nothing vested in the old technology, can be looked to as a fertile source of innovation. More recently still, other institutions appear to have taken on an increasingly important role in environmental innovation: universities, government laboratories, industry consortia, etc. Their emergence is consistent with the model of technological innovation as an interconnected network of various players, operating co-operatively in an innovation system.

ENVIRONMENTAL POLICY INSTRUMENTS

The following analysis categorises environmental policy instruments into different types, based on the most important and common instruments in current use. For each of the instruments, discussion is offered of the kinds of effects it is likely to produce on technological change. The conclusions reached are rooted both in theoretical and empirical literature, but often represent judgements and opinions rather than clearly proven propositions. They are used here as working hypotheses. **Table 1** summarises and compares the findings concerning the probable technological response of firms to different types of environmental policy instruments: radical innovation, incremental innovation, continuing innovation and/or technology diffusion. **Table 2** predicts which types of firms are most likely to respond to different environmental policy instruments: firms in the polluting sector, firms newly entering the market and/or firms in the environmental goods and services sector.

Table 1. Environmental policy instruments and types of technological response

	Radical innovation	Incremental innovation	Continuing innovation	Technology diffusion
Product standards	X	XX	X	XXX
Pre-market approval	X	XXX	N/A	N/A
Product bans	XXX	X	XX	XXX
Performance standards	X	XXX	XX	XX
Technology specifications	X	XX	X	XXX
Facility permits	X	XX	X	XX
Pollution charges	X	XXX	XXX	XX
Emissions trading	X	XX	XX	X
Environmental subsidies	XX	XXX	XX	XXX
Producer responsibility	XXX	XX	XX	X
Information disclosure	X	XXX	XXX	XX
Voluntary agreements	X	XX	XX	XXX

X = LOW, XX = MEDIUM, XXX= HIGH

Source: Heaton, 1997.

Table 2. Environmental policy instruments and types of firms responding

	Regulated firms	New entrants	Environmental goods and services firms
Product standards	XX	XX	XXX
Pre-market approval	XXX	X	X
Product bans	XXX	XXX	X
Performance standards	XX	XXX	XX
Technological specifications	XX	X	XXX
Facility permits	X	X	X
Pollution charges	XXX	X	X
Emissions trading	XXX	X	X
Producer responsibility	XXX	XXX	X
Information disclosure	XXX	X	XX
Voluntary agreements	XX	X	X

X = LOW, XX = MEDIUM, XXX= HIGH

Source: Heaton, 1997.

Product standards

Regulatory requirements that specify the environmental and/or safety characteristics of consumer and industrial products are in widespread use throughout OECD countries. Generally, such standards are imposed on products already in the marketplace and would therefore be expected to prompt changes in technology. In fact, what seems to have happened in most recorded examples is quick substitution of an existing technology (whether substitute or redesign), not true innovation. Lead and solvent-based paints, urea formaldehyde foam insulation and small engines furnish some historical examples of products for which technology to solve environmental problems was moved "*off the shelf*." In such cases, some cost and/or functional changes may have affected consumers, though not in a major way. Technological effects of product standards may thus be characterised as incremental innovation, although this may be widespread throughout the industry.

One case of product regulation has been studied more extensively than any other regulatory history: automobiles. Three major regulatory regimes – pollution control, fuel economy and safety – were applied to the industry, with perhaps the most intense attendant controversy of any regulatory situation. The following are among the most important lessons concerning the relationship between product regulation and technological change in these circumstances:

- Stringent regulation can successfully effect major change, but with some politicisation and uncertainty; long lead time and some structural change in the affected sector should be expected.

- The natural tendency in a highly mature, concentrated industry is to focus on the least disruptive technological solution, in this case, the catalytic converter.

- The most innovative, quickest responses may come from small firms in the industry and new players (e.g. pollution control equipment manufacturers).

- The changes in automotive technology interacted strongly with and probably would not have been possible without major changes in the external technical context, notably the application of computerised controls.

- The power of economic incentives – notably fuel taxes – is clearly demonstrated from the experience of Europe and Japan.

Pre-market approval

Pre-market approval systems for pharmaceuticals, pesticides and toxic chemicals are virtually ubiquitous throughout the OECD. Although they differ in procedures and implementation, the basic feature – government scrutiny and culling of new technologies prior to commercialisation – is constant. The directness of the control these regulatory structures exert on product innovation has given rise to widespread concern about retarding its rate. It has also yielded a better-developed body of literature, both conceptually and empirically, than for any other policy instrument. By and large, these studies show that the innovation effects of pre-market approval systems are more complicated than they would suggest at first glance.

In the pharmaceutical area, early cross-country studies in the 1970s asserted that US regulation, more stringent than that in the United Kingdom, was leading to a smaller number of new drugs. Later research debunked the negative myths from such simple studies, showing major differences in rates of scientific progress across therapeutic classes as explanatory factors, as well as positive compensating effects of increased consumer confidence in new drugs (Link and Mitchell, 1976).

What did emerge clearly, however, were the effects pre-market approval have on the period of research and development: *lengthening it and increasing its cost*. Recognising that these impacts were likely to decrease the rewards to new drugs – and thereby disrupt the innovation cycle in a highly research-intensive industry – the US Congress was prompted in the mid-1980s to increase the life of pharmaceutical patents. Since then, much less concern has been voiced about the regulatory climate for traditional pharmaceuticals, although the biotechnology industry has perhaps been affected as the existing regulatory regime has been applied – sometimes slowly and/or uncertainly – in a revolutionary new technical context.

The advent of pre-market approval for toxic substances in the United States in the mid-1970s prompted a flurry of studies. These showed a significant short-term drop in the numbers of new chemicals on the market due to anticipation of regulation before, and uncertainty about, its implementation during the first few years. A negative longer term effect also seemed to be in progress: disadvantage to small firms and specialty chemicals producers who found it harder to absorb the higher fixed costs (particularly from testing) induced by regulation, than did their larger rivals (Ashford and Heaton, 1983).

Another negative effect of pre-market approval systems is shown in the experience with pesticide regulation (Benbrook, 1990). Here, regulatory scrutiny of existing products is exercised in a much less thorough or stringent manner than for new products. This tends to create a bias against new technology and in favour of the status quo. Increasing consumer demand for pesticide-free agricultural products has established a major motivation for innovation outside of the traditional chemical-based agricultural paradigm. Regulatory standards appear to have lagged behind rather than led this phenomenon.

Product bans

Bans – the most severe regulatory command possible – have been applied almost exclusively to chemical products. PCBs, phosphate detergents, asbestos, urea formaldehyde foam insulation, DDT and other pesticides, leaded gasoline and CFCs offer the main examples. Each represented a major environmental hazard – often global in scale – towards which nations within the OECD and elsewhere have acted with a surprising degree of consonance. Most of these cases have been studied extensively (Cook, 1996; Hartje, 1985).

Product bans always result in a change in technology. The nature of change can range, however, from simple substitution of readily available products, processes or components (e.g. aqueous cleaning replacing CFCs) to incremental innovation (reformulated detergents or gasoline) to radical changes that restructure an industry (PCB substitutes produced by new firms which totally displaced the sole US producer). It is important to note, however, that the immediate responses are rarely the ones ultimately dominant over the long-term, particularly when they represent a fairly innovative new approach. But it must also be recognised that for every banned product, the industrial system has ultimately found ways to re-accommodate to acceptable new technology – though not immediately or without cost and disruption.

Almost all banned substances have been mature technologies. Because the economic and technological stakes are so high in such situations, the public decision process has typically been highly politicised and unpredictable. Sometimes, the dominant technological players – for example, Bayer, Germany's major PCB producer – sought to delay implementation of the ban until their position in the substitute technology was secured. At other times, they left the field altogether, as in the case of Monsanto, the major US PCB producer. Such circumstances present a fertile opportunity for "outsiders" – such as new firms with new concepts, customers of the producer of the banned substance, foreign firms, etc. – to challenge the technologies dominant before the ban, which is a unique aspect of this policy instrument.

The history of bans illustrates clearly what theories of innovation would predict as the results: a combination of mature technologies and firms adept at incremental change but unwilling to depart from the essential status quo; technological invaders with new concepts; and the potentially disruptive power of radical innovation. These experiences suggest a fundamental lesson for environmental policy: dramatic policy initiatives can produce technologically beneficial results over the long term, provided the transient disruptions and costs can be sustained.

Performance standards

Performance standards are widely used as an environmental policy instrument to implement process controls for air pollution, water pollution and hazardous waste management. The theoretical case for performance standards as a means of promoting technological innovation is compelling: they combine a clearly-articulated technological demand with flexibility in solving it. Regulatory critics and reformers routinely endorse performance standards as a superior alternative to technology specifications on this rationale.

The problems with realising this theoretical advantage derive in large part from the difficulty in putting a true performance standard into practice. Most so-called performance standards are in fact based on assumptions about what the best available technology can achieve. Many of them, thus, require little or no technological changes from firms already at the state of the art. Some performance standards are phrased in terms so vague (e.g. *maximum feasible emission reduction*) as to undercut their objectivity; others are coupled with monitoring requirements so specific as to leave the polluter few control options in practice.

During the 1970s, when the debate about what type of pollution control standards to apply was particularly intense, a number of studies looked at the impact of performance standards – on copper smelters, mercury effluents, vinyl chloride, asbestos, cotton dust and lead. The findings from these studies show the following patterns of technological response to regulation in the form of performance standards (Ashford *et al.*, 1985; Lurie, 1993):

- High volume, mature sectors were resistant to major change, although very amenable to environmental monitoring and process controls that improved efficiency.
- Significant process innovations occurred in response to stringent regulations that gave firms in the regulated industry enough time to develop comprehensive strategies.
- Smaller firms and potential new entrants tended to develop more innovative responses.
- The environmental goods and services industry provided compliance strategies that were at best incrementally innovative, but which diffused fast, due to their lack of disruption and acceptability to regulators.
- Regulatory flexibility toward the means of compliance, variation in the requirements imposed on different sectors, and compliance time periods were aspects of performance standards that contributed to the development of superior technological responses.

Technology specifications

De jure technology specifications – regulatory commands to utilise a particular technology – rarely exist, because few circumstances justify such a technological straight-jacket. Nevertheless, there are many situations is which the range of compliance options acceptable to regulators is known to be small enough that a *de facto* specification arises. This is particularly true for air and water pollution and hazardous waste control. However, technology specifications foreclose the possibility of an immediate innovative response, since they are based on already available technology. While one would hope that incremental changes in technology and regulatory up-dates would go hand in hand, in fact regulatory decision-making is typically cumbersome enough to make this unpredictable, at best.

Specification standards do furnish a compelling force for technology diffusion. Since they are typically based on the best technology in use in leading firms or available in the environmental goods and services industry, one tendency is to force laggards up to the state of the art. Another, of course, is to provide a major market for environmental goods and services firms. Assuming that this is a competitive market, the force for innovation among various environment industry providers should be strong. While anecdotes tend to confirm this, no study has looked systematically at innovation in this sector. The modelling work from the 1970s that did address the issue made no more than the obvious point that specifications encourage diffusion, not innovation (Magat, 1979).

Facility permits

Construction, siting and pollution permits are a widely used mechanism through which regulators scrutinise industrial technology, ensure compliance with applicable laws and involve various parties, particularly local citizens, in environmental decision-making. In many countries, the environmental permitting process tends to be separate for air, water and waste. It is, from the point of view of firms, a major source of delay, red tape and uncertainty. However, from a public point of view it is one of the major ways of gathering information about and influencing the technological decisions of firms. There has been virtually no analysis examining the innovation effects of the environmental permitting process. This is unfortunate, since permits, by virtue of their comprehensive *ex ante* scrutiny of new industrial facilities, undoubtedly have a major impact on technological change.

A conventional wisdom has nevertheless developed about the impact of facility permitting on technological change (Heaton and Banks, 1997). Most observers see it having major negative effects on innovation, both among the regulated industry – which may well postpone the installation of new equipment so as to avoid scrutiny – and among the more innovative segments of the environmental goods and services industry – whose new compliance techniques may be greeted with regulatory scepticism, delay and uncertainty. Recognising such complaints, regulators in the United States have begun to adopt at least three strategies, all of which seem to hold the potential to improve the climate for environmental innovation:

- So-called fast tracks through the permitting process for innovative technologies.
- Verification or compliance certification of promising new technologies.
- Consolidated permitting, in which regulators package air, water and waste controls in a single decision-making process.

Pollution charges

Pollution charges as an instrument of environmental policy are the subject of a rich literature – almost all of it authored by economists – that has persisted throughout the 25-plus years of modern environmental policy. There is also by now substantial experience with pollution charges and taxes for both air and water, almost all of it in Europe: Dutch, French and German water pollution control and financing systems; Swedish and Norwegian nitrogen oxide and sulphur charges; and widespread pollution charges placed on leaded automotive fuels.

The major virtue of pollution charges, long emphasized in the literature, is that, in contrast to regulatory fiat, they should produce an "efficient" level of pollution abatement. But it has also long been recognised that setting the "right" level of charge is a formidable undertaking. The practical compromise struck in most of the pollution charge systems now in existence is: first, to couple charges with command and control regulation, so as to ensure minimally acceptable levels of environmental quality; and second, to structure fees with both revenue-raising (e.g. for waste treatment) and incentive effects in mind.

The effect of economic incentives has been the subject of a major review by the OECD (OECD, 1997*b*). In the area of pollution charges, the results suggest that they have been effective as a means of achieving environmental improvement, financing and creating a continuing incentive to technological change. Other studies show that the dynamic effects of pollution charges and other levies may vary due to the mediating effects of the environmental policy process and other innovation-relevant determinants (Hemmelskamp, 1997). Extrapolating from these and other studies, it seems reasonable to conclude that pollution charges and taxes should be a powerful tool to promote continuing technological change in affected firms. Since at present the level of charges is not deemed sufficiently high in most cases, the tendency is towards incremental innovation, with radical improvements as yet unlikely. These effects occur almost exclusively in the regulated sector, affording little opportunity for more widespread structural change.

Emissions trading

Emissions trading is a more recent entry into the realm of economic incentives than pollution charge schemes. Tradable permits have been embraced aggressively in practice primarily in the United States, where they are now under experimentation for water effluents in specific locales, air pollution in general, sulphur emissions as a particular programme, lead refinery emissions and CFC phase-outs. Even more than pollution charges, emissions trading is focused on "efficient" pollution abatement, since it gives lesser-cost abaters (or situations) the ability to transfer their savings to higher-cost circumstances. Many environmentalists have endorsed the approach in recent years as a more flexible and less costly approach to achieve at least as much environmental protection as the status quo regulatory levels. Trading schemes are administratively complicated, and considerable time has been spent in the United States to put trading into place, including a public market in air pollution rights on the Chicago commodities exchange.

The OECD study of economic instruments documents the effective use to which trading has already been put (OECD, 1997*b*). However, it emphasizes that knowledge about the effects on technological change is minimal. One of the striking conclusions about the trading systems in the United States to date is that trades have been more frequently internal than external (i.e. balancing pollution from different sources within corporations or limited localities). This raises the possibility that trades are more a balancing device within overall emissions targets than a stimulus for technological change. The limited potential of trading is reinforced by the fact that only polluters exchange rights, which tends to circumscribe the role of outsiders, in the environmental goods and services industry or elsewhere, in participating in the technology development. This relatively closed circle argues, as well, that incremental innovation, rather than radical change, is the most likely result. That said, emissions trading appears to be enjoying increasing approval throughout the relevant US communities, and therefore may well become a staple of future environmental policy in that country, if not in other OECD countries. This should be a positive force for encouraging continuing environmental innovation.

Extended producer responsibility

Extended producer responsibility can refer either to the legal liability imposed on manufacturers of hazardous products for the harm those products cause, or to the gathering set of requirements to maintain a stewardship over the life-long environmental consequences of goods sold (OECD, 1997*a*). Rules of liability have, of course, long been a staple of the legal system in all OECD countries – although they vary greatly in form and stringency. Product stewardship is a much newer concept and is being expressed in various ways. Perhaps its most extensive application has taken root in Germany, where so-called "take-back" laws require manufacturers of consumer products (e.g. refrigerators) to accept them for disposal at the end of their commercial life span. Another variant is the so-called "Responsible Care" concept, endorsed by the American Chemical Manufacturers Association, in which the companies recognise their responsibility to police the environmental consequences of their products "from cradle to grave".

Rules of legal liability tend to be a perennial subject for debate, largely because they are thought to be more favourable toward injured parties. Hardly any of this discussion has shed light on the issue of how legal liability affects the propensity to innovate. Many business people assert that product liability laws force them into a risk-averse posture – largely a result of the uncertainty in application of the laws – which retards the introduction of new products before their characteristics can be predicted. Consumer advocates often accept this diagnosis, but argue that this is in fact the purpose of the laws: to encourage safer, more predictable products. No one has tested an equally plausible proposition: that product liability laws tend to encourage innovation by driving unsafe products off the market.

Product stewardship policies may also offer a powerful and benign approach to far-reaching design changes of real benefit to the environment. The main virtue of extended producer responsibility is that it changes the time-frame and range of factors that appear in the design space of an engineer. Whereas without such responsibility, companies might ignore the after-effects and re-use potential of the products they sell, once the new legal framework is imposed, they will undoubtedly design with such factors more prominently in mind. Anecdotal evidence from German automobile and consumer product companies suggests that a major re-conceptualisation of the design process is underway, in which environmental factors are an “integral” part. US chemical manufacturers frequently make the same point. And in Japan, engineering theorists are discussing the development of a new field – “inverse engineering” – which thinks backwards from the environmental consequences of wastes to the initial design problem. Assuming this trend continues, it should be an important force for environmental innovation, particularly among companies which would, in the traditional regulatory model, have been the major targets of *ex post* product standards, as well as among younger firms willing to experiment with new approaches.

Information disclosure

Information policies cover a wide range of initiatives pertaining to both public disclosures of environmental performance and monitoring requirements. The former are intended to alert, protect and give the public choices about the environmental consequences of business activity. The latter is more oriented to regulatory compliance and enforcement. Both types of initiatives are in a fertile period of experimentation. Public disclosure policies have proliferated worldwide, with sometimes surprising results. Regulatory enforcement may well be on the brink of a new era as major improvements in monitoring technology make real-time information – and hence, incentive-based regulatory systems – a realistic possibility.

One of the most interesting information policies is the US Toxic Release Inventory (TRI). Put into operation around the beginning of the 1990s, TRI was the first reporting requirement to look across environmental media to try to assess total toxic emissions. As the quantities and sources reported were surprising – to both firms and local communities – there appears to have been a strong motivation to improve overall environmental performance, with consequent emissions reductions reported. A similar initiative may be unfolding in the United States in the water pollution context, as municipal systems have recently been required to disclose contaminants to their customers. Lastly, many multinational corporations and developing countries are taking a strong interest in environmental disclosure requirements.

While information disclosure may seem a mild motivator in comparison to traditional regulatory command and control, it has at least two major virtues for technological change. First, to the extent that the information systems are holistic and range across various environmental media, they are likely to produce comprehensive technological changes rather than the end-of-pipe, medium-specific fixes that have so often been the response to regulation. Second, because information requirements evolve over time, they are likely to promote incremental technological improvements as well. Beyond the impact on polluting firms, information policies help to create markets for monitoring and control technology. Such technologies represent only a niche in the overall environmental goods and services industry, but one in which major innovation seems to be on the horizon, often connected to the larger technological transformations in progress in industrial process control and manufacturing systems.

Voluntary agreements

Voluntary agreements usually represent an end-point in a process of negotiation between public authorities and firms over the degree and nature of environmental improvements that will occur in a given context.

Given this dynamic, use of the term “voluntary” may even be something of a misnomer, since firms are usually responding to pressure rather than volunteering change. Voluntary agreements have been rare - though increasing – in the United States. The European experience seems more fruitful, and Japanese public policy has long made voluntary agreements one of its staple instruments (Wallace, 1995). The European Environmental Agency recently estimated that there are over 300 voluntary agreements in force in the European Union; the Netherlands leads with about 100 agreements followed by Germany. Examples include a French project to increase recycling of cars and car parts; Swedish and Danish agreements for recycling packaging; a German agreement on reducing greenhouse gases by 20% by the year 2005; a Dutch scheme to reduce chemicals pollution; and a Portuguese agreement on reducing pollution in the pulp and paper industry.

One of the major virtues of voluntary agreements is that they assign the initiative for specifying change to the party with the knowledge to design it and the means to implement it – i.e. the firm. Other major virtues include flexibility and realistic time-frames, all of which should in principle promote sensible technological responses in the target firm. On the other hand, it is hard to foresee major change or radical innovations arising from voluntary agreements. According to the European Environmental Agency, the absence of reporting and monitoring requirements in most voluntary agreements is a serious obstacle to assessing their impact on the environment. One type of voluntary agreement which shows more promise is environmental compacts, which are negotiated arrangements that substitute for and/or supplement regulation. Pioneered in the Netherlands, and enjoying increasing discussion now in the United States (Heaton and Banks, 1995), environmental compacts tend to differ from other voluntary agreements in a number of respects:

- They tend to be structured on a contractual basis, committing parties on all sides to participation.

- The range of participants may be wide, including community and labour representation as well as government and industry.

- Compacts are often firm-specific, but may also pertain to an industry as a whole, frequently committing signatories to a common, co-operative agenda.

- A commitment to and outline of technological changes over time is a standard element.

PROMOTING ENVIRONMENTAL INNOVATION

Reforming process regulations

The traditional forms of environmental regulation – government-initiated, "command and control" type technical standards – are in no danger of disappearing anywhere in the OECD. Too much has been invested in these policy instruments for them to be abandoned; they enjoy citizen acceptance; regulated firms and the environmental goods and services industry have adjusted to them; and the attractiveness and/or feasibility of economic incentive systems is too far from proven to justify turning wholesale in a new direction. However, the time is past when regulation could be characterised as a major force for radical "technology forcing" in industry. For the foreseeable future, regulation is likely to constitute a relatively predictable stimulus to incremental innovation along established pathways of environmental and technical improvement. Within this expectation, new regulatory approaches could nevertheless substantially enhance the climate for innovation. These new approaches include:

- ***Shifts away from technology specifications*** or "Best Available Technology" standards. These should be replaced with true performance standards; such standards should be deliberately structured to exceed current best practice over a reasonable time period; they should apply equally to new and old facilities, thus levelling the playing field between new and old technology and equipment.

- ***Revision of monitoring requirements*** to promote real-time monitoring, routine environmental accounting and intelligent process control so as to turn performance standards into meaningful realities.

- ***Regulatory flexibility*** to encourage alternative compliance methods; emissions trading systems are one way to accomplish this; expedited regulatory procedures for innovative techniques, firms and technologies are another, and should include testing/evaluation of new environmental technologies.

Reforming product regulations

Product regulatory systems tend to set up a perverse dynamic with respect to the innovation process: by controlling one part of the process heavily (i.e. first commercial introduction) and relatively de-emphasizing others (e.g. disposal), such regulatory frameworks both penalise innovation and exacerbate environmental problems. What is needed by way of reform is a new policy package for product regulation that levels the playing field between old and new technologies and among different environmental hazards. This package might include:

- ***Promoting product stewardship*** throughout all phases of product life; legal responsibility for product disposal should be encouraged not only as a means of tackling waste disposal but also as a stimulus to innovation in the integration of environmental factors into product design.

– ***Modifying new product scrutiny*** to the minimum necessary for public safety and establishing procedures to expedite testing and approval; for example, time deadlines for regulatory action, default approvals in cases of delay, and extended patent protection where regulatory scrutiny limits effective patent life.

– ***Emphasizing control of hazardous products*** should take priority; shifting the balance of resources in product regulatory regimes toward scrutiny of “bad actor” existing technologies; distribution of hazard information, regulatory requirements, internationally harmonised approaches and bans of especially hazardous products would all increase the incentive for environmentally beneficial innovation.

Implementing new approaches

The use of public information systems as an instrument of environmental policy has been one of the field’s most interesting recent developments. Another extremely important trend is the parallel development of environmental management and accounting systems in private corporations. What is striking about both is their departure from traditional command and control regulation as well as their consistency with market forces. While related in principle and potentially in practice, public information and reporting requirements and private management and accounting systems have not been co-ordinated to any extent.

The environmental management systems now proliferating worldwide tend to combine elements of corporate environmental accounting and quality management practices into systems that are supposed to provide companies with a holistic approach to the achievement of environmental goals. While governments have not yet embraced environmental management systems as public policy instruments, the corporate sector – particularly large corporations – has done so vigorously. For example, ISO 14000, the internationally recognised standard for corporate environmental management systems, has spread with amazing speed throughout the international business community. Many commentators have hailed such developments as a new era in corporate and international environmental governance. In the United States, the Multi-State Working Group on Environmental Management Systems (MSWG) has finalised protocols and pilot projects for implementing the ISO 14001 system, which is expected to help meet public policy goals and may lead to changes in environmental policies.

In spite of this enthusiasm, it is important to realise that corporate environmental management systems – ISO 14000 most notably – do not commit their adherents to new substantive environmental goals, but only to a process of assuring what has already been pledged or regulated. It would thus be overly optimistic to expect that they will result in much innovation over the short term. Over the longer term, however, there is a major virtue to such systems in that they provide a continuing, comprehensive examination process – certainly the most of any policy instrument – and thus may create a continuing incentive for technological and management changes. The following are means for further realising the innovative potential of information and environmental management approaches:

– ***Greater acceptance of corporate data*** from environmental accounting in regulatory permitting and enforcement contexts, in exchange for making such information publicly available.

– ***Greater use of ISO 14000 certification*** as a complement to regulation, thereby perhaps reducing the extent of regulatory oversight needed.

– ***Enhanced role for private standards bodies*** and industry associations in monitoring the environmental records of corporations and publishing trend data.

– ***Development of environmental indicators***, new and improved versions at the firm, industry and economy level, with public support.

Combining policy instruments

A drawback to the research on environmental policy and technological change is that it tends to treat policy instruments as discrete variables, when in fact, several are almost always applied in combination. In many countries, economic instruments are being used to a greater extent as complements to more traditional forms of regulation with positive results. **Table 3** is intended to address the question: *What combination of policy instruments is likely to produce what degree of environmentally beneficial innovation in what contexts*? Three factors enter the table's implicit equation:

1) Type of policy instrument.
2) Goal of innovation.
3) Magnitude of the innovation effect.

Table 3. Magnitude of innovative responses to environmental policy instruments

	Mature industry	New entrant	Environment industry	Product change	Process change	Resource use	Management
Product standards	+			+			+
Pre-market approval		-		-			+
Product bans	++	++		++			
Performance standards	+	+	+		+	+	
Technology specifications	-	–	++		+		
Facility permits	-	-			–	+	
Pollution charges	++	++			++	++	+
Emissions trading	++	-	-		++	++	+
Producer responsibility	++	+		++		++	++
Information disclosure	++	+		++	++	++	++
Voluntary agreements					+	+	+

Source: Heaton, 1997.

The first two of these are arrayed along the vertical and horizontal axes, respectively. In cells of the matrix, + or - signs then indicate the tendency (positive or negative) and magnitude (single or multiple signs) of the effect on innovation (blank cells are neutral). The table can offer conclusions by reading horizontally or vertically. For example, reading horizontally, it shows that *product standards* may have mild positive effects on product change and management attitudes in a mature industry. *Product bans* would have much more radical effects on mature industries and also encourage the entry of entrepreneurs producing new products. Economic instruments *(pollution charges* and *emissions trading)* can have significant effects on technological change, since in theory one of their major advantages rests in dynamic efficiencies. While regulation tends to provide a strong single stimulus to technological change, economic instruments may give a continuing impetus to innovation. Therefore, combining regulatory approaches with economic instruments offers the promise of an optimal technology outcome. In general, economic instruments should be used more frequently as subsitutes for – and complements to – regulations from the standpoint of overall technological effects.

Reading vertically, one may conclude that mature industries are most stimulated to innovative responses in terms of changing products by *product bans*, *economic instruments* and *extended producer responsibility*. While the innovation behaviour of both mature industries and new firms tends to be negatively affected by *technology specifications*, these can provide a boost to the environmental goods and services sector which produces new products and processes to meet pre-set technical requirements. Achievements in eco-efficiency in terms of reduced resource use, redesign of products and processes and development of managerial environmental awareness may best be stimulated through newer instruments such as *extended producer responsibility* and *information disclosure*.

Achieving policy coherence

Many countries lack a consensual environmental policy process within which the synergies from combining policy instruments can be realised; one exception is the Netherlands which has a long-term environmental policy plan (Wallace, 1995). There also tends to be a lack of connection between the policies and institutions promoting technology development and those concerned with the environment. Bifurcating policy in this manner tends to produce piecemeal solutions. In addition to combining environmental policy instruments to achieve technological change, these instruments need to be joined to technology policy instruments within a more comprehensive framework to be truly effective. Several changes in administrative practice could speed the trend towards more holistic environmental technology strategies:

– ***Establishing a long-term, comprehensive framework for environmental policy*** within which different government agencies and industrial sectors set goals, make informed choices and avoid the creation of an adversarial policy environment.

– ***Increasing co-ordination among environmental and technology agencies*** in identifying and supporting development of important environmental technologies, and assessing technological possibilities for increasing eco-efficiency with a view towards implementing policy packages to this end.

– ***Making more use of pro-innovation implementation strategies***, such as emissions trading schemes, manageable transition periods, flexibility in enforcement for firms trying innovative approaches, closer technical co-operation between industry and government regulators, certainty of objective but flexibility on how to achieve it, etc.

– ***Assessing the technology impact of environmental policies***; this could be done through ongoing innovation surveys which question firms as to the sources of innovation and already indicate the influence of regulatory policies; conversely, more could be done in the scientific community to assess the environmental effects of technology policies.

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PUBLIC/PRIVATE PARTNERSHIPS FOR DEVELOPING ENVIRONMENTAL TECHNOLOGIES

SUMMARY

Because continued technical innovation is vital to achieving sustainable development, joint government-industry action needs to foster the development of clean industrial products and processes. Public/private research partnerships are key to developing environmental technologies that can contribute both to sustainable development and industrial competitiveness. Such partnerships leverage private investments in environment-related innovation and direct it towards critical research needs.

Partnerships are necessary because certain obstacles to the development and diffusion of clean technologies remain. Most governments are facing severe constraints on their research and technology budgets; as environment-related research is not a large component, public/private partnerships offer a means of doing more with less. They stimulate innovation in integrated processes and clean technologies that might not be pursued by industry on its own, since end-of-pipe treatments may appear cheaper and payback periods on clean technology investments appear long. Partnerships help overcome information gaps, seek to involve smaller firms in diverse sectors, and can demonstrate the cost-effectiveness of new technologies. They also facilitate interdisciplinary research and enhance networking among actors in the innovation process, including enterprises, universities and government research laboratories and institutes.

The technical focus of research partnerships for sustainable development now shows a marked convergence. The emphasis has definitely shifted from end-of-pipe to clean technologies. To address climate change concerns, energy-related and environmental considerations are being merged. The fact that most government programmes include the development of pre-competitive clean car technology is not a coincidence nor is the frequent focus on the development and use of biotechnology for addressing environmental problems. Other shared research topics include recycling (of wastes, consumer goods, hazardous gases, etc.), the development of closed-loop production processes, and the greening of product design through Design for Environment projects. They point to the emergence of an international consensus on technologies that are needed for sustainability and may be the source of industrial competitiveness in the near future. Public/private research partnerships, by virtue of their ability to cut across institutions, firms and sectors, are a valuable mechanism for generating a wide range of technological innovations from pre-competitive, breakthrough discoveries to technologies nearing commercialisation.

INTRODUCTION

Inducing appropriate innovations in environmental technology, especially cleaner products and cleaner production processes, is a growing concern of technology policy in the OECD area. Until this decade, technology and environmental policies have not been adequately integrated, partly because technology was not regarded as potentially able to solve environmental problems and partly because regulatory approaches were oriented not towards stimulating new technology development but towards “best available technologies”. For this reason, technological innovations did not generally seek to improve the environment and contribute to sustainable development.

This situation, however, has changed, as a range of techniques – largely end-of-pipe technologies such as desulphurisation equipment and catalytic converters – have contributed significantly to pollution abatement. Advances in energy conversion and energy efficiency technologies have also made positive contributions to improving the environment. Technology is increasingly regarded as the source of solutions to many environmental problems, particularly as environmental technology has shifted from end-of-pipe solutions to cleaner processes and products. These developments have given rise to a growing industrial subsector which produces environmental goods and services (OECD, 1996). Some recent studies present evidence of the positive impact of environmental technologies on competitiveness and productivity (Repetto *et al*., 1996; Porter and van der Linde, 1995). Technology foresight exercises in OECD countries list environmental technology as a critical area for the next century (OECD, 1998*a*).

Environmental protection is normally considered an externality and is therefore prone to market failure. In many cases, because public benefit can be obtained only at considerable cost to industry, investment and technological innovation are insufficient, hence the importance of public policy in stressing environmental protection and in implementing policy measures to induce adequate and appropriate technological innovation.

Environmental regulations have been the most important public policy tool for stimulating industrial innovation in environmental technology. In the past, the need to comply with regulations forced industry to develop and adopt various pollution control technologies and equipment. A few decades of experience with environmental regulation have shown that the kind of regulatory measures adopted influence the type and extent of industry’s innovative efforts. Designing regulatory measures that maximise efforts to generate suitable environmental technologies is of fundamental importance. In this context, recent experience in OECD countries indicates that innovations in environmental technologies are best stimulated when various regulatory measures and economic (market) instruments are flexibly combined so as to take into account industry-specific and, in some cases, firm-specific contexts. Well-designed technology policies, including public/private research partnerships, can also help combine and direct various mechanisms to induce cost-effective cleaner process and product innovations.

The science-based, as well as the interdisciplinary and intersectoral, nature of environmental technology implies that this area is also prone to systemic failure. In order to optimise environmental innovation, insights from advances in various basic and applied sciences and engineering disciplines must be integrated. Interaction between research in environment-related areas, ranging from basic science to interdisciplinary fields such as ecology, climatology and toxicology and to technical areas such as environment monitoring and engineering, will be needed to generate breakthroughs as well as to progress incrementally. However, the breadth and depth of interaction needed is inadequate at present in most OECD research communities. This highlights the government’s role in enhancing co-operation among the relevant actors and linking the university, industry and government research sectors to address important environmental problems.

COMPARISON OF PROGRAMMES

Rationale

The characteristics of the development of environmental technologies point to the importance of government's role in stimulating appropriate research and innovative activities. Except for energy, public budget allocations for environmental research and development have not been large. A significant part of publicly funded energy R&D, with an annual budget allocation (including demonstration projects) of about USD 10 billion, is directed to developing cleaner and more efficient conversion and end-use technologies (International Energy Agency, 1997). Apart from energy research, an estimated USD 2.5 billion is spent annually by OECD governments on environmental R&D. However, the research in government laboratories or universities has mostly been directed to fundamental science and ecological concerns, with relatively little going to technology. Governments have turned to industry for environment-related technological innovation and relied on other mechanisms, particularly regulatory regimes, to stimulate technological development by the private sector.

More attention is now being given to using public funds to leverage private spending on research and development, particularly through partnership schemes. Public/private partnerships, or joint government/industry efforts in funding and/or executing research and development, are one useful mechanism for addressing both market and systemic failures in science and technology (Guy *et al.*, 1998). They can address industrial under-investment in environmental technologies by lowering the financial burden of investment in research and providing an incentive to undertake long-term R&D projects to develop cleaner processes and products. They can therefore direct industry's innovative efforts towards fields and technologies deemed most promising for sustainable development. Partnerships can also address systemic failures by bringing together different research sectors (government laboratories, enterprises and universities) and different scientific and engineering disciplines, thus strengthening the linkages needed to foster innovation for sustainable development.

Public/private partnership programmes for developing environmental technologies in the OECD countries examined in this document were shaped on the basis of the different paths along which government technology programmes had evolved. Japanese government technology programmes have always sought to increase the competitiveness of Japanese industry, and industry-government co-operation to develop technology has a fairly long history. In order to increase competitiveness, collaboration between government research institutes, universities and enterprises was regarded as vital, and the technology programmes of the Ministry of International Trade and Industry (MITI) were designed to enhance research and development links between these actors. In this sense, without explicitly being government-funded partnership programmes, most MITI technology programmes have, in effect, been such. Over the last few decades, MITI has sponsored projects that pioneer industrial technology essential for developing the national economy and which required substantial funds, long lead times and high risks, and which the private sector was unlikely to undertake alone. For example, the *Very Large Scale Integrated Circuit* project is considered to have played a role in fostering the Japanese semiconductor industry.

Research and development projects on environmental (and energy) technologies have accounted for a growing share of MITI technology programmes. Among the first projects under the *Large Scale Projects Programme* initiated in 1966 were the flue-gas and the heavy oil desulphurisation projects, which helped enable the Japanese industrial sector to control SOx emissions, while at the same time fostering the subsector of the machinery industry engaged in the production of pollution control equipment (Fukasaku, 1992). Energy technologies became a main area in the 1970s with the launching of the renewable energy technology development programme, the *Sunshine Programme*, in 1974 and the energy conservation technology programme, the *Moonlight Programme*, in 1978. In the wake of the petroleum crisis, the main rationale behind these programmes was to develop alternative energy technologies for the purpose of energy security; environmental objectives were secondary. Since then, however, the latter objective has grown in importance. In 1990, the *Global Environment Industrial Technology Research and Development Programme* was launched. In 1993, these three programmes and elements from other programmes, such as the new chemical processing project and the diesel and lean-burn engine NOx catalyst development project were merged to form the *New Sunshine Programme*, in which environmental technologies, especially those related to protection of the global environment, such as CO_2 fixation technologies, constitute a major part.

In the United States, the concept and the term "*partnership*" reflect the reorientation of publicly supported research and development over the last two decades. In the initial decades after World War II, it was assumed that US government research to fulfil government agency missions, such as defence and space, would automatically, and in fact did, result in "spin-offs" to the industrial sector and enhance its technological development. This paradigm worked well while America enjoyed undisputed leadership in science and technology. However, in the 1970s and 1980s, the increasing industrial competitiveness of other advanced countries started to erode US technological supremacy, causing economic decline and job losses. By then, the new technologies created by the spin-off process and which underpinned American technological superiority, e.g. computers, software, semiconductors, advanced materials and manufacturing technologies, were increasingly driven not by military but by commercial demand. The spin-off process no longer functioned effectively (Brody, 1996).

Under these circumstances, a new paradigm emerged, in which the government acts as a partner with the private sector to develop technologies to improve the competitiveness of American industries and create jobs. In the 1980s, the US government launched partnership programmes that were specifically designed to enhance US competitiveness, *e.g.* the *Advanced Technology Program* and the *Manufacturing Extension Partnership*. In energy technology, programmes such as the *Clean Coal Technology Program* operated by the Department of Energy since 1986, have brought innovative power generation technologies based on coal and natural gas – such as fluidised bed combustion, gasification-combined cycle and fuel cells – closer to commercialisation. Such programmes seek to correct under-investment by the private sector in technological development and are becoming more prominent for the development of environmental technology.

Similarly, the European Union (EU) started research and development partnership programmes in the mid-1980s under the Framework Programmes, with the 5th Framework Programme (1998-2002) now being initiated. In addition to promoting scientific advance and industrial competitiveness in areas such as the environment, partnership programmes in Europe have aimed to increase European integration by involving enterprises and research bodies from different countries in joint projects. Sectoral programmes such as the *Thermie Programme* have sponsored energy technology demonstration projects on a shared-cost basis (maximum 40% Community support) since the 1970s. In the current phase, the programme's aims are to improve energy efficiency in both demand and supply, promote the use of renewable energy, and encourage cleaner use of coal and other solid fuels. Through these projects, the programme seeks to contribute to other EU objectives such as reinforcing the competitiveness of EU industry [especially small and medium-sized enterprises (SMEs)] and promoting employment and export potential.

While in the past public/private partnerships have evolved differently, a certain convergence now seems to be emerging, with the launching of partnership programmes to develop environmental technologies. Many OECD governments have started to view environmental technologies as capable of contributing not only to realising social goals, but also to increasing industrial competitiveness and job creation. Thus, the rationale for government programmes for developing environmental technologies in partnership with industry derives from a mixture of economic and environmental motives and a recognition of the need to address both market and systemic failures in the innovation area.

Structure

There are broadly two types of public/private partnerships in the environmental area. Environmental technologies may constitute a part of existing research partnership programmes or be created as special joint schemes directed towards environmental concerns. Thus, one category includes public/private research partnership programmes for promoting technological innovation in general or with a broader scope than just environmental technologies. Examples are Technology Partnerships Canada, where environmental technologies constitute one of three areas, along with enabling technologies and defence and space technologies. Similarly, the LINK programme in the United Kingdom is directed towards promoting partnerships in several technology fields, of which environment is only one, while the EU Framework Programmes cover a wide range of science and technology areas. In Sweden, the Competence Centre Programme has created joint industry/university research centres to develop a number of new technologies, some of which are directed to environmental innovation. Finally, the US Manufacturing Extension Partnership addresses environmental concerns as one aspect of its services to develop and diffuse technology to industry. The integration of environmental technology into broader government schemes shows the heightened attention being given to environment-related innovation and can give environmental research more stability and funding over the long term; however, environmental technology schemes still constitute a very small part of these larger programmes.

In the second category are those partnership programmes devoted exclusively to environmental/energy research topics. Examples are Japan’s New Sunshine Program, Finland’s Environmental Cluster Research Programme, Germany’s Research for the Environment programme, the Netherlands’ Economics, Ecology and Technology programme, Norwegian NORMIL 2000 or the United States’ Technology for Sustainable Environment scheme. These programmes are relatively new and their durability and continued funding will primarily depend on their results and impact from an environmental and economic perspective. Also in this group are partnership schemes directed to development of a specific environmental technology, such as the US Department of Commerce’s Partnership for a New Generation of Vehicles (PNGV). These projects may end when they have successfully developed the intended innovation, such as the “clean car”. Thus, there is wide variation in project duration; depending on the type of programme, it may range from long-term projects that continue for five to ten years to short-term ones that last less than a year. Also, the funding for partnership programmes is sometimes dependent on independent evaluations and assessments, which are becoming more widespread for all government-funded research and development.

Technologies

Most public/private partnerships to develop environmental technologies aim to push forward the frontier in technical areas of potential relevance to both competitiveness and sustainable development. As opposed to more basic scientific investigation, they are usually concerned with development of technology – products, processes and systems of potential commercial use. They are also usually focused on enabling technologies, those that could spawn a host of spin-offs. The type of technologies the partnership programmes aim to develop thus range from pre-competitive, breakthrough-type technologies – as in the case of the MITI programmes – to those that target technologies closer to commercialisation – as in the case of Technology Partnerships Canada. In some programmes, such as the UK LINK programme, research and development priorities are directly related to the government’s technology foresight exercise, which identifies important technical areas in need of research.

In general, environmental technology partnership programmes have seen a similar broad shift in research priorities. Many government programmes a decade or two ago aimed to develop end-of-pipe technologies in order to assist industry compliance with environmental regulations. In recent years, instead, partnership programmes focus on cleaner process and product technologies. For example, in Germany, the acknowledged cost-effectiveness of cleaner technology and the potential for increasing resource productivity have spurred this trend *(Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie*, 1998). In the effort to focus on cleaner processes and products, some programmes, such as the United States' Technology for Sustainable Development, even explicitly exclude end-of-pipe technologies. Focus is also diversifying from specific local pollution control techniques to technologies that address energy efficiency and more diffuse environmental issues such as waste treatment and climate change.

Despite considerable variety in the focus of these partnerships, the ubiquity of certain technologies reflects the existence of international consensus on innovations that are crucial for enhancing industrial competitiveness and achieving social objectives in the immediate future. Thus, several countries are concerned with the development of pre-competitive technologies associated with a radically more fuel-efficient clean car. These include the US Partnership for a New Generation of Vehicles (PNGV), the UK LINK Foresight Vehicle Programme, the clean car project of Technology Partnerships Canada, and Japan's New Sunshine Program project on lean-burn engine technology. The US PNGV is a classical R&D partnership scheme and "probably the best US example of an environmentally integrated technology programme" (Oldenburg, 1998). It involves joint efforts in the funding and execution of research to develop a more fuel efficient car by the "big three" American car manufacturers and a number of federal government agencies and their affiliated research institutes as well as universities and supplier companies.

Another common theme is the integration of energy efficiency into environmental partnership programmes and a greater merger of environment and energy programmes in order to address climate change concerns. In Japan, energy efficiency has for some time been a key element of environmental technology development efforts, and energy policies have addressed environmental goals through the promotion of energy conservation (Fukasaku, 1995). The rationale behind the merging of MITI energy and global environmental technology programmes in 1993 was the integration of energy and environmental dimensions in technology development. Similarly, in the early 1990s, the US Department of Energy launched programmes, such as the Industries of the Future Initiative and National Industrial Competitiveness through Energy, Environment and Economics, to develop technologies that integrate energy efficiency and cleaner processes. The EU Framework Programmes are also moving towards better integration of environmental and energy research on enabling technologies. More recently, the pursuit of broader eco-efficiency goals, i.e. increasing the efficiency of both materials and energy as inputs and reducing wastes and emissions as outputs, has been highlighted, for example by the Finnish Environmental Cluster Research Programme.

Greener design, especially for products, is attracting special attention in programmes such as the US Design for the Environment and the Swedish Design for Environment in SMEs. The US project, sponsored by the Environmental Protection Agency, aims to help business incorporate environmental considerations into the design of products and processes through co-operative projects. The Swedish programme is based on the idea that product development and design are becoming more important for achieving environmental goals, and that new technologies and approaches are needed to decrease or prevent product impact on the environment from a lifecycle perspective.

Biotechnology is also the subject of several public/private partnerships on environmental technologies. The use of biotechnology or micro-organisms can contribute to soil remediation and improved water quality as well as to making industrial processes and products cleaner through the application of innovative processes that enable a reduction of energy and materials consumption and a diminution of emissions and wastes in manufacturing (OECD, 1994; 1998*b;* 1998*c*). Germany's Research for Environment Programme is closely linked to other government programmes, including the Biotechnology 2000 Programme, and the interlinkage is expected to lead to the development, for example, of higher-yielding plants through progress in genetic engineering which substantially reduces the application of chemical pesticides, to lower cost pesticides (compared to chemicals) and to more environmentally acceptable biological water purification processes. In Japan, the environmental technology part of the New Sunshine Programme includes a project on fixation of carbon dioxide through biological techniques using bacteria and micro-algae, as well as a range of projects for developing a new generation of industrial processing and product technologies based on biotechnology, such as the development of bioreactors and biodegradable plastics. The Research Institute of Innovative Technology for the Earth (RITE), which participates in many of the New Sunshine projects, focuses its research efforts on developing innovative industrial processes based on new biological or chemical processes that would contribute to the protection of the global environment.

Another theme frequently found is waste management and recycling, as in the case of the German Research for the Environment programme. Recycling, specifically the conversion of post-consumer and industry waste into building materials, is one target of the environmental projects of Technology Partnerships Canada. Recycling of non-ferrous metals using liquid natural gas is under study in the Japanese New Sunshine Programme, and recycling of ozone-depleting substances is being examined in Japan's Research Institute of Innovative Technology for the Earth. In addition, MITI organises a range of waste management and recycling technology research programmes. Several projects are directed to developing closed-loop production processes, such as the UK LINK Waste Minimisation through Recycling, Re-use and Recovery in Industry programme. The Dutch Economics, Ecology and Technology programme supports research projects on the treatment and reduction of industrial process water. Norwegian NORMIL 2000 also includes a number of projects on waste treatment.

Funding

Public/private research partnerships are generally based on cost sharing, and companies as well as universities and research institutes affiliated to government agencies perform the R&D. Part of the value of public/private partnerships is the leverage effect obtained from a small government investment. Few of these schemes are large, either compared to the overall R&D effort of which they are a part or to the larger-scale mission or scientific programmes most governments maintain. The focus has been on broad impact R&D, where a small amount of funding may have large payoffs for the economy and the environment, as well as on challenging industry to take on higher risk projects, but with greater potential payoff, than they otherwise would.

Cost-sharing ratios differ from programme to programme or even from project to project within a programme depending on the number and the kind of research actors involved and the stage of the research and development effort. In many schemes, industry provides 50% or more of matching finance. In the case of Technology Partnerships Canada, which is perhaps aimed at innovations closest to the market, industry provides 70-75% of finance with the remainder provided by the government. The general trend is greater public funding for activities closer to basic research and increased private participation as the commercialisation stage nears. Cost sharing by government and industry, which takes different forms, seems to encourage effective private-sector participation. In addition, in most countries, industry has expressed its preference for cost-sharing over purely government-financed projects. There is a growing trend towards such partnerships in overall government R&D funding.

Public funds are normally given as grants, but in some cases, such as Technology Partnerships Canada, funds are given as repayable investments. Here, government and industry share costs, risks and returns on investment. The government share of investment is repaid through royalties on successful projects, and these repayments are recycled back into the fund for future investments in research partnerships. In order to increase returns, some environmental technology R&D programmes include mechanisms for promoting the commercialisation of developed technologies as well as their wider dissemination. Examples are the various Design for Environment schemes directed at environmentally sound product development. Technological spin-offs from research partnership programmes are one of the broad goals, so all schemes might give greater attention to means for more broadly disseminating the results of the R&D conducted.

Partners

The trend in environmental technology partnership programmes is towards involving more public and private performers of research and enhancing collaboration among them. Networking among actors for the purpose of promoting interdisciplinary research is one aim of partnership programmes. Personnel mobility and collaboration is enhanced through project teams that cut across institutional and public/private boundaries. Thus, a preference may be expressed for co-operative endeavours that cross sectoral, institutional and/or national boundaries. This stems from the desire to promote technical cross-fertilisation, ensure dissemination of results across a range of potential users and/or to increase regional integration, particularly in the case of EU programmes.

Partnership programmes usually provide funding for research to single firms or to consortia of industrial enterprises. The general technical areas may be outlined in advance, with industrial consortia or firms submitting relevant project proposals. This is particularly the case for the larger partnership programmes aimed at several technical fields of which environment is only one. Here, as for all projects, programme awards may be based on the technical excellence of the recipients and their proposals as well as on their ability to contribute to the development of the innovation in question. Another general benefit of these schemes is that, even in the proposal stage, they tend to bring together disparate groups to pursue common technology development opportunities through the establishment of horizontal consortia, vertical producer-supplier relationships and linkages between large and small companies.

Except for the Swedish Design for Environment in SMEs, most programmes target firms of all sizes; however, smaller firms are involved in most of the programmes examined and many include special provisions to attract SMEs. In the case of the UK LINK programme, out of the more than 1 300 companies presently involved, some 700 are SMEs, and the programme "actively encourages" the involvement of SMEs. The German Federal Foundation for the Environment was set up with a major aim to support SMEs' activities in the environmental field. Technology Partnerships Canada, an investment programme, targets environmental technologies nearing commercialisation, which are often developed by innovative smaller firms. An important characteristic of partnership programmes is that they can help SMEs to realise their innovative potential by leveraging investments in developing environmental technologies.

Many programmes aim to involve not only government agencies and industrial firms but also universities and other research bodies. Academic institutions and other research groups tend to participate in co-operative relationships with firms. Some programmes – such as the US Environmental Technology programme and the German Research for Environment scheme – explicitly stress the promotion of interdisciplinary research so as to involve researchers and research approaches from a number of differing scientific and engineering disciplines and institutions. In cases such as the European Framework Programmes, environmental research has been conducted primarily by consortia of universities and research institutes, and there is now a stress on involving more industrial enterprises.

Programmes also differ in the number and type of government agencies involved. Some programmes are run by only one government agency, as in the case of Japan's MITI programmes, while many others involve a number of government agencies, such as the US PNGV and the German Research for the Environment scheme. There seems to be a trend towards involving more government agencies as well as research bodies and companies in funding and execution so as to promote networking and linkages. In the Dutch Economics, Ecology and Technology programme, although participation of one industrial partner in a project is required, preference is normally given to projects to be undertaken by larger consortia involving public research institutes, universities and private firms.

ANNEX: SELECTED OECD PROGRAMMES

Canada

Technology Partnerships Canada. Technology Partnerships Canada (TPC) was created in 1996 as an integral part of the Jobs and Growth Strategy. For this programme, the Canadian government reallocated resources from existing programmes of Industry Canada and added new funds from the Jobs and Growth Strategy to be invested in projects that foster international competitiveness, innovation and commercialisation, as well as increased investment in Canada. TPC is exclusively an investment programme, in which the government makes fully repayable investments. The government funds about 25-30% of the project cost and strictly adheres to this ratio for the purpose of leveraging private investments. Both the government and industry share the costs, risks and return on investment, the government's share of investment to be repaid through royalties on successful projects. Repayments are recycled back into the fund for future investments. TPC is administered through a Special Operating Agency with an interdepartmental committee, which provides co-ordination with other programmes. A Technology Advisory Board of private sector experts and industry leaders, chaired by the Minister of Industry, assesses market trends and ensures that TPC targets appropriate investments, usually financially sound SMEs with high-risk projects and identified market opportunities.

Environmental technology is one of the three technology categories supported by this programme. The view taken is that the growing international commitment to sustainable development and environmental protection will likely make environmental industries a fast-growing knowledge-intensive sector that will provide highly skilled jobs and economic growth. The other two categories are: *i)* enabling technologies, including advanced manufacturing technologies, advanced materials, biotechnology and selected information technologies; and *ii)* aerospace and defence technologies. Environmental technologies supported by TPC are air pollution control technologies, water and wastewater treatment technologies, clean car/transportation systems, climate change technologies, and pollution prevention and eco-efficiency technologies, including soil remediation and recycling.

Activities eligible for TPC grants include: *i)* those related to the development and demonstration of products, processes and technologies, including related research and development; *ii)* pre-production activities, including the development of production capabilities that might determine where an industry locates; and *iii)* studies related to a project that could be supported under one of the other eligible activities. Private partners are assessed on a project-by-project basis. The assessment criteria include: potential for generating economic benefits to Canada, demonstration of technical and managerial ability to complete the project, competitiveness in the global market, ability to finance its share of the costs and repay the contribution, the extent to which the project involves alliances between producers and users of technology that can build links between large and small firms for supplier development and job creation, and the extent to which the project supports sustainable development and offers solutions to priority environmental problems.

In its first year of operation, Technology Partnerships Canada approved 30 projects of which six were for development of environmental technologies. Applicants were mostly geographically dispersed SMEs. The technologies included development of closed-loop, zero-effluent technologies for the pulp and paper industry; turnkey systems to clean up pollution in printing plants; commercial-scale demonstration of a system for converting post-consumer and industry waste into marketable pallets, sheets and roofing tiles; commercialisation of a 250-kilowatt proton exchange membrane fuel cell power plant; gaseous fuel engine control systems; and a cost-effective method for detecting potential leaks in natural gas and liquid hydrocarbon pipelines. These projects are expected to generate or maintain a considerable number of jobs (Industry Canada, 1998).

Finland

Environmental Cluster Research Programme. Under the headings of eco-efficiency, co-operation and environmental entrepreneurship, this programme, which involves firms, public authorities, and the research and education sectors, seeks to increase Finnish industry's competitive edge and facilitate innovation through collaborative projects that cross disciplinary boundaries and stimulate networking among researchers and users. The initial research projects are being implemented between 1997 and 2000 and are directed at improving eco-efficiency through the application of lifecycle analysis and materials flow assessment in agriculture, forestry, basic metals and water management. The projects focus on integrated prevention and control of emissions, reduction and re-use of waste flows and prevention of eutrophication. These projects also address the efficient use of energy as part of the effort to reduce emissions and to address climate change. The Ministry of the Environment co-ordinates the programme, and funding and implementation are shared by the Ministry of Trade and Industry, the Technology Development Centre (TEKES) and the Academy of Finland.

Germany

Within the federal government, several departments with different tasks are responsible for environmental research and the development of environmental technologies. General research funding is the responsibility of the Federal Ministry of Education, Science, Research and Technology (BMBF), which earmarked budget funds of DEM 740.9 million for environmental research and environmental technology in 1997. Other federal ministries, particularly the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), initiate and fund environmental research within their special responsibilities. Together they spend about DEM 300 million per year, bringing the federal government's annual expenditure for environmental research and environmental technology to more than DEM 1 billion.

Research for the Environment. As in most countries, environmental policy and research in Germany in the 1970s were oriented towards developing end-of-pipe solutions to air and water pollution to comply with regulations. As in the case of Japan, this approach "made a particularly significant contribution to improving air and water quality in Germany and also led to the fact that German environmental technology has been able to win a considerable share of the world market" (*Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie*, 1998). In the 1990s, the emphasis has shifted to developing cleaner products and processes; this is explicitly stated in the new Research for the Environment programme, the successor to the Environmental Research and Environmental Technologies programme which operated between 1989 and 1994. Research for the Environment is a comprehensive research programme intended to "support scientific initiatives aimed at developing, together with partners from industry, new environmental technologies and/or new concepts of environmental engineering and use" with a view to establishing environmental centres of excellence to undertake research and technological development and the marketing of environmental products.

Co-ordinated by the Federal Ministry of Education, Science, Research and Technology (*Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie*, BMBF), the new programme aims to explore more environmentally acceptable paths for technology and product development and achieve significant increases in resource productivity. Development of cost-effective environmental protection measures is considered important for securing jobs and strengthening the competitiveness of German industry. The government wishes to pursue a precautionary environmental policy, including the uncoupling of consumption of resources and environmental pollution from economic development. Rather than developing end-of-pipe environmental technologies, the new programme views "environment as human habitat" whose protection would require an interdisciplinary approach involving a broad spectrum of scientific disciplines. Hence, the programme is linked with other government research programmes. For example, contributions from the Biotechnology 2000 Programme may lead to the uncoupling of economic and population growth through progress in genetic engineering which enables the development of higher-yielding plants.

In contrast to the former Environmental Research and Environmental Technologies programme, which was funded by BMBF alone, the present programme is a joint research programme of all participating federal departments and co-ordinated by BMBF. Funding also comes from other public sector agencies and research bodies as well as state sources, companies, private foundations and the EU. Research for the Environment focuses on three areas of research: *i)* regional and global engineering of the environment; *ii)* approaches to a sustainable economy; and *iii)* environmental education. The second area concerns the development of environmental technologies and emphasises cleaner products and processes, replacement of ecologically critical substances, and recycling. The programme stresses waste minimisation, development of environmentally friendly products and processes, recycling and re-use, and energy efficiency. Ecological design of products, cleaner production, closed loop production processes, waste management, soil remediation and water treatment are the areas on which co-operative research efforts are to focus.

Japan

In Japan, most environmental technology development programmes are run by the Ministry of International Trade and Industry (MITI) as part of the range of technology projects the Ministry sponsors. MITI’s environmental technology projects are managed by its affiliated agency, the New Energy and Industrial Technology Development Organization (NEDO), originally founded in 1980 to promote the development of alternative energy technologies in the wake of the second petroleum crisis. Industrial technology development, including environmental technologies, has subsequently been added and has become a major undertaking. MITI entrusts (*itaku)* projects with funding to NEDO, which becomes the project implementing entity. NEDO, in turn, commissions private firms to perform the research and, in some cases, universities and research institutes who normally organise themselves into research associations to undertake the research. MITI usually fully funds the initial stages of the projects; however, as the project nears the commercialisation stage, the participating industrial firms fund at least a part (normally about one-third) of the necessary research expenses. MITI programmes aim to develop risky innovative technologies that require a fairly long time to develop (five to ten years).

New Sunshine Program. Many of Japan’s environmental technology projects belong to the New Sunshine Programme created in 1993 by merging the Sunshine (renewable energy), Moonlight (energy conservation) and the Global Environment Industrial Technology Research and Development Programme. Therefore, MITI’s environment technology programmes have a special focus on technologies that are of relevance to the protection of the global environment, especially CO_2 fixation and adsorption. It is also a characteristic of MITI’s environmental technology programmes that many address energy efficiency as well. Also, the renewable energy and energy conservation components of the programme have projects with environmental objectives such as cleaner coal technology. The merger was intended to facilitate the pursuit of innovations that would simultaneously address energy and environment issues in the framework of sustainable development.

The environment technology projects include the New Generation Chemical Processing Technology Project, which aims to transform the chemical industry into an energy- and resource-efficient and environmentally friendly sector by developing innovative chemical processes using new catalysts. It also includes a project for developing de-NOx catalysts for lean-burn and diesel engine emissions. Projects to develop innovative technologies for the global environment include those related to fixation and recycling of CO_2, environmentally friendly industrial processes, and reduction of hazardous emissions or wastes. Specifically, the CO_2 fixation projects are: *i)* environmental assessment techniques for carbon dioxide ocean sequestration; *ii)* biological CO_2 fixation technology using bacteria and micro-algae; *iii)* chemical CO_2 fixation technology using membrane process and conversion into methanol through hydrogenation; and *iv)* high-temperature CO_2 fixation technology (Ministry of International Trade and Industry, 1998; New Energy and Industrial Technology Development Organization, 1998).

The New Sunshine Programme projects on industrial processing technologies include:

- Next generation bioreactor systems.
- Hydrogen generation technology using micro-organisms.
- Catalysts for converting methane into methanol and photo-catalysts for generating hydrogen from water.
- Technology for removing impurities from steel scrap.
- Recycling of non-ferrous metals using liquid natural gas.

Research Institute of Innovative Technology for the Earth. Some of NEDO's *itaku* contracts in the field of environmental technology go to the Research Institute of Innovative Technology for the Earth (RITE), a foundation (*zaidanhojin*) set up in 1990 as the implementing body of New Earth 21. This is a research and development scheme to rejuvenate the planet over the next century through the development of innovative energy-environment technologies, which the Japanese government presented to the Houston Summit in 1990. More than half of its funding comes from the private sector and the rest from MITI. In contrast to NEDO, which itself does not carry out R&D, RITE is a research entity with its own research staff and laboratories. Private firms directly participate in the research projects undertaken by RITE, and each participating firm appoints a research team and a leader responsible for executing its part of a RITE project. A few national research institutes as well as universities normally collaborate in carrying out these projects. In addition, promotion of international co-operation is important, and RITE operates a co-operative research grant scheme and enhances international researcher interaction through conferences and seminars.

While most environmental technology projects undertaken by RITE address long-term, breakthrough technologies, RITE has also created a genuine partnership scheme, the Joint Research Programme of Technological Development in the Private Sector, to promote the development of environmental technologies which are closer to commercialisation. RITE funds half of the project's expenses and private firms cover the rest. Funding is normally for three to five years. Project themes are chosen from: *i)* technologies to reduce the emission of greenhouse gases or their recovery, fixation and re-use; *ii)* more energy-efficient production processes using biotechnology and new chemical engineering methods; *iii)* treatment, recovery or recycling of ozone-layer-depleting substances and other hazardous substances or development of their substitutes; and *iv)* air, water and soil pollution monitoring techniques (Research Institute of Innovative Technology for the Earth, 1998).

New Industry Creative Technology Research and Development Promotion Programme. This was launched in 1995 by NEDO, which has made a broad call for proposals for innovative research projects to be undertaken by collaborating research teams involving universities, national research institutes and industrial firms, with the objective of creating new industries that promote economic growth and secure energy supply. Energy-conservation-related environmental technology is one of the three areas being promoted under this programme. The other two are innovative industrial technologies and technologies suitable for commercialisation by SMEs. This programme enables post-doctoral fellows belonging to a university to be sent to collaborating industrial firms to carry out research (New Energy and Industrial Technology Development Organization, 1997).

Waste Management and Recycling Technology R&D. MITI also organises a range of waste management and recycling technology programmes which are run by NEDO. The programme comprises projects aiming to develop technologies to treat and/or recycle a wide range of wastes ranging from CFCs (chloro-fluorocarbons) to municipal sludge. Specific projects include: regeneration technology for used refrigerant CFCs and CFC decomposition technology; iron and non-ferrous metals recycling technology; plastics recycling including for PET bottles and thermal recycling methods; low-quality waste paper re-utilisation technology; recycling of coloured glass bottles; eco-cement production technology using municipal waste and high-speed composting technology; waste treatment technology using oil-alternative energy; and techniques for treating hazardous and refractory chemicals.

The Netherlands

Economics, Ecology and Technology 1997. This is a genuine partnership programme launched by the Dutch government in 1996 to support new long-term strategic R&D projects in the environmental field, for the purpose of strengthening the link between economic growth and sustainable development. The programme supports selected projects to be funded and executed by a consortium of at least two partners, one of which must be a private firm. Research expenses are shared by the government and the participating partner (research institute, university, private company), with a minimum funding requirement of 25% of the portion performed by that partner. The government funds a larger proportion of the more basic phase of the research. Average project duration is four years. Through tendering rounds, 12 and 14 projects were selected in 1996 and 1997, respectively, in the fields of industrial process water treatment, industrial waste treatment, environmentally sound product development, renewable resources, and sustainable energy and traffic and transport (EET Programme Office, 1998).

Norway

NORMIL 2000. Launched in 1996 for a five year period, the programme of the Research Council of Norway is aimed at promoting environmental technology research activity in Norway by supporting high risk projects with significant scientific content as well as market potential on a partnership basis, with 50-70% private funding share. An important characteristic is a close co-operation with sector specific programmes and priority is given to some sectors such as building and construction, process industry, transport, and oil and gas. Examples of projects include automatic identification and sorting out of different plastics in household waste, and technology for compact and economical removal of nitrogen from waste water. There are many projects on waste treatment and environmental monitoring technology.

Sweden

NUTEK Competence Centre Programme. In 1993, the Swedish National Board for Industrial and Technical Development (NUTEK) launched an effort to promote university-industry interaction in research to contribute to industrial productivity. The programme’s aim is to develop industry-related competence centres to conduct co-operative research in specific technical areas. There are now approximately 30 competence centres. Universities administer the centres’ activities and contribute to their financing by providing a base organisation and other resources; about 160 industrial companies are now participating in the programme. The following competence centres focus on research related to environmental technology:

- Competence Centre for Surfactants based on Natural Products (SNAP). Located at the Royal Institute of Technology (KTH), this centre is a collaboration between NUTEK, KTH and industry to increase knowledge and experience regarding new environmentally sound surface-active substances such as detergents, derived entirely or partly from natural products.

- Competence Centre for Amphiphilic Polymers from Renewable Resources (CAP). Located at Lund University, this centre is a collaboration between NUTEK, the university and industry, to carry out research on the preparation and properties of polymers using renewable resources such as cellulose and starch.

- Minerals and Metals Recycling Research Centre. Located at Lulea University of Technology, this centre organises collaborative programmes with Swedish industry in developing technologies for recycling and re-use of metals and minerals wastes and for minimising and stabilising metal wastes.

- Centre for Environmental Assessment of Product and Material Systems. Located at Chalmers University of Technology, this is a ten-year centre for co-operative research in the field of product-related environmental assessment, with a focus on developing tools for lifecycle assessment.

Design for Environment in SMEs. The partnership programmes discussed so far target firms of all sizes. NUTEK has just launched a programme exclusively targeted at smaller firms, the Design for Environment in SMEs. Based on the understanding that the driving force behind industrial environmental activity is shifting from environmental regulation to enhancing competitiveness through the adoption of environmentally sound products and processes, and that the focus of environmental activity is shifting from manufacturing processes to product development and design, the new programme aims to promote design for environment (DFE), *i.e.* "development of measures which decrease or prevent the impact of products on the environment in a lifecycle perspective" (NUTEK, 1998), and to develop green marketing methodology. In NUTEK's view, smaller Swedish firms are lagging in taking advantage of this trend and are in need of the following:

- Design for environment methodology adapted to the conditions and needs of SMEs.
- Integration of environmental design methodology in operational tools, such as the ISO 9 000 or 14 001 system.
- DFE implementation with increased profitability as the primary decision parameter.
- Industry or product-specific data accumulation through co-operation within groups of companies.

The new programme attempts to promote DFE in Swedish SMEs in order to strengthen their growth potential and contribute to the shift to a sustainable society. It aims to develop DFE tools and methodology based on results of earlier projects in the area, both domestic and foreign, and to diffuse them to a broad group of Swedish SMEs. Tools/aids from adjacent areas will be further developed and new ones produced, so that environmental considerations can be integrated into companies' daily product-related work. The tools and methodology are to be tested and demonstrated through product development in pilot companies. The project will produce manuals, software and training programmes that support product development activities in SMEs. The results will be disseminated through different company networks, *e.g.* trade organisations and industrial research institutes.

Projects are to be organised and managed not by individual companies but by firm networks, industrial research institutes or universities, in some cases involving customers of the participating SMEs. Firm networks are to be formed from groups of pilot companies that co-operate through exchange of experience and data. The networks are based on supply chains or common interest in the development of certain products. A steering committee has been created to implement the programme and NUTEK is to ensure co-operation with actions and competencies in the related areas of environmental technology, eco-management, product development technology, SMEs and technology transfer, and information technology. The programme started in April 1998 for a three-year period, with a possible renewal of another three years before which a review is to be carried out.

Environmental Management in SMEs. Another NUTEK programme targeted at SMEs aims to develop environmental management systems in SMEs by providing three types of services: *i)* information dissemination through free telephone service, documents, seminars and conferences; *ii)* financial support and guidance to regional and local projects; and *iii)* co-operation and co-ordination with national and regional organisations and authorities and exchange of experience and search for best practice through an international network.

United Kingdom

Promoting co-operation between industry and the research base is the central objective of the LINK programme, which includes projects in environmental technology. Launched in 1986, LINK is the government's principal mechanism for supporting collaborative research between industry and the public sector. The general purpose is to enhance the competitiveness of UK industry and the quality of life through support for pre-competitive science and technology and to encourage industry to invest in research leading to commercially successful products, processes, systems and services. While all companies and multinationals with a significant manufacturing and research base in the United Kingdom can participate, the involvement of smaller firms is actively encouraged. More than 1 300 companies – including some 700 SMEs and 195 research base institutions – are involved. The research topics of LINK programmes respond to priorities identified under the Technology Foresight initiative conducted in 1993.

LINK covers a wide range of technology and generic product areas from food and bio-sciences, through engineering to electronics and communications. Typically, a number of government departments and research councils collaborate to fund each LINK programme, and each programme supports a number of collaborative research projects. A typical project lasts two to three years and brings together industrial partners who draw up a collaboration agreement and who are placed under a well-defined project management framework provided by the Programme Management Committee. Membership on the Committee is drawn from the participating partners, which assess proposals, provide guidance, monitor progress and encourage commercial exploitation. Public partners provide up to 50% of the eligible cost of a LINK project with the balance of funding coming from industry. The benefit of this scheme to the participating industrial firm is access to high-quality researchers whose knowledge can underpin innovation within the firm. At the same time, public researchers can work in partnership with industrialists to apply knowledge and expertise to exploit commercial potential.

A recent review gave a positive assessment of the outcome of the LINK programme, which was seen as providing: *i)* activities to promote commercial exploitation and wider dissemination of research results; *ii)* industrial access to research base knowledge and skills; *iii)* industrial relevance for academic research; *iv)* research training for graduate students and brokerage of new partnerships between industry and the academia; and *v)* a programme-based approach which creates a network of participants who share ideas and information. There are currently 58 LINK programmes in all; in addition to the two described below, other LINK programmes related to the environment include those in sustainable agriculture, health, and bio-sciences and bio-engineering (Department of Trade and Industry, 1998*a*).

Waste Minimisation through Recycling, Re-use and Recovery in Industry. The Waste Minimisation through Recycling, Re-use and Recovery in Industry project, announced in May 1995, involves research aimed at the development and implementation of cost-effective technologies for recycling, re-use and recovery of materials within manufacturing. It focuses on: *i)* development of materials that facilitate recycling, recovery and re-use; *ii)* recovery of both useful and hazardous components; *iii)* development of novel separation technologies; *iv)* water treatment for re-use; and *v)* developing methods for lifecycle assessment, process system modelling and process optimisation. In short, the programme aims to develop closed-loop production processes. This programme is jointly sponsored by the Engineering and Physical Sciences Research Council and the Department of Trade and Industry.

Foresight Vehicle Programme. Announced in July 1997, this LINK programme aims to implement the vision created by the Foresight Transport Panel by stimulating the UK automobile supplier base to develop and demonstrate a clean, efficient, lightweight, telematic, intelligent, lean vehicle which will satisfy increasingly stringent environmental requirements while meeting mass market expectations for safety, performance, cost and desirability. "It is about creating new technology options which will underpin our future transport policy and our need for sustainable development” (Department of Trade and Industry, 1998*b*). Thematic groups covering the seven research areas of advanced structures and materials, alternative propulsion, advanced electronics, telematics, power train, manufacturing processes, and design and engineering, bring together representatives from UK industry, academia, research and technology organisations, user groups and public sector bodies to identify technology needs and define the research focus. The programme is jointly sponsored by the Department of Trade and Industry (DTI) and the Economic and Social Research Council (ESRC) with additional support from the Ministry of Defence and Department of Environment, Transport and the Regions.

United States

In the United States, programmes that aim to develop environmental technologies in the industrial sector are organised by the Department of Energy (DOE), the Department of Commerce (DOC) and the Environmental Protection Agency (EPA). EPA has programmes that promote the development and diffusion of environmental technology, including green products and manufacturing technology. Some of these are run jointly with the National Science Foundation. EPA and DOE have launched a number of voluntary partnership and technology transfer programmes. In general, DOE programmes attempt to pursue energy efficiency as well as cleaner technologies and industrial competitiveness. A related US goal is creating a globally competitive US environment industry, including developing better technology policies and improved strategies to accelerate the market acceptance of innovative technologies.

Clean Coal Technology Program. This Department of Energy (DOE) partnership programme started in 1986 with the objective of expanding the menu of innovative pollution control options to curb the release of acid rain pollutants. The original recommendation for the programme came from the meetings of the US-Canada Special Envoys on Acid Rain who were charged with finding the solution to the transboundary problem of acid rain. Included was the recommendation to launch a government-industry programme to demonstrate new innovative environmental technologies on a matching fund basis between the private sector/state and the federal government. Emphasis was placed on industry initiative.

The industry partners are responsible for both demonstration project proposal and management. The programme’s originally intended five rounds of competition have been completed, and the leveraging effect has resulted in two-thirds of the programme’s total costs coming from non-federal sources. The first projects were principally more cost-effective environmental retrofit technologies, such as low-polluting coal burners and post-combustion sulphur-removing devices which have now moved into commercial application. In the last two rounds of competition, a broader spectrum of projects which could meet longer-term emission requirements and increase energy efficiency have been sought, including advanced “super clean” power generation systems, such as integrated coal gasification combined cycles and pressurised fluidised bed combustors, which offer high-technology approaches for keeping coal a viable energy option in the next century.

Industries of the Future Initiative. This is a collaborative effort between DOE’s Office of Industrial Technologies and seven energy-intensive industries (steel, aluminium, metalcasting, glass, chemicals, petroleum refining and forest products) to identify and develop high-risk, high-payoff technologies to enhance their competitiveness while fully integrating energy and environmental considerations. The programme involves: *i)* drafting the vision for the industry; *ii)* formulating a technology road map, and *iii)* funding needed research and development to realise the goal. Once step *i)* is completed, the industry and DOE make a formal agreement for collaborative efforts whereby DOE provides cost sharing to many R&D projects identified through this process.

Partnership for a New Generation of Vehicles (PNGV). PNGV is a research partnership programme sponsored by the Department of Commerce, which aims to develop technologies for a new generation of vehicles with up to triple the fuel efficiency of today's midsize cars without sacrificing affordability, performance or safety. This "supercar" is intended to curb weight by 40% over the baseline of 3 200 pounds; have improved aerodynamic characteristics, reduced friction, flywheels, batteries or ultracapacitors for the engine; and demonstrate increased fuel efficiency of 80 miles per gallon or BTU (British Thermal Unit) equivalent (metro-highway) rather than the 26.6 mpg of the baseline. It is also assumed that the new car would be designed to comply with Clean Air Act requirements, and that it would have a recyclability objective of at least 80% instead of the 75% industry average today. At the same time, it would maintain the performance, size and utility standards of today's vehicles.

The programme was launched in 1993 based on the recognition that the development of a new generation vehicle required efforts and initiative at the national level, and that the success of the programme is important to maintain the competitiveness of the American automobile manufacturing sector and to preserve jobs. By increasing fuel efficiency, US dependence on oil imports is expected to decrease, and emissions of carbon dioxide would be reduced. In the development process, the programme aims to increase productivity by upgrading manufacturing technology through the adoption of agile and flexible manufacturing and reduction of costs and lead times while reducing the environmental impact.

This programme involves a number of federal government agencies and their affiliated research institutes including the Department of Commerce and its National Institute of Standards and Technology (NIST); the Department of Defense; the Department of Energy and its ten national laboratories which have research programmes in gas turbines, hybrid vehicles, alternative vehicles, alternative fuels, fuel cells, advanced energy storage and lightweight materials; the Department of Transportation's National Highway Traffic Safety Administration (NHTSA); the Environmental Protection Agency and its National Vehicle and Fuel Emissions Laboratory (NVFEL); the National Aeronautics and Space Administration; and the National Science Foundation. Private partners are the United States Council for Automotive Research (USCAR), a research consortium consisting of the "big three" American automobile manufacturers, and a number of suppliers and universities. The DOE programmes are maintained through co-operative research and development agreements (CRADAs) with the USCAR consortium; a "master" CRADA has been developed as the model for all such efforts within PNGV which eliminates renegotiation of the terms of the agreement.

Research is conducted on a cost-shared basis. The federal government funds a proportionately larger share for fundamental research, but as R&D moves closer to commercialisation, industry provides an increasing share. Under PNGV, teams of scientists and engineers from federal government laboratories work with their counterparts at Chrysler, Ford, General Motors and more than 350 automotive suppliers and universities. PNGV has adopted strict time limits for each stage of the development effort. In 1994, the government and industry jointly identified technology areas in which advances are needed to meet PNGV goals, and by the end of 1997, PNGV narrowed the selection of technologies to four key system areas on which to focus resources: hybrid-electric vehicle drive (HEV), direct-injection (DI) engines, fuel cells and lightweight materials. Between 1998 and 2000, each car company is expected to produce concept vehicles and by 2004, prototypes would be produced by each firm.

The National Research Council (NRC) has been conducting independent reviews of the programme annually, and these have been an essential tool for assessing the technical progress of PNGV. Recommendations from NRC's first three reports prompted improvements in the PNGV programme. The fourth review, released in April 1998, found that the PNGV is making steady progress towards meeting its goals, including assessing the potential of each candidate system and identifying critical technologies necessary to make each system viable. Good progress was seen in the past year in: *i)* all aspects of the four-stroke direct injection programme; *ii)* fuel cells; *iii)* development of full-size cells of lithium-ion batteries and of nickel metal hydride batteries; *iv)* organising and co-ordinating its efforts in the area of power electronics and electrical systems; and *v)* evaluating lightweight candidate materials. NRC further concluded that "meeting the PNGV cost goals within the PNGV time frame will be an enormous challenge" and that reducing the cost of these technologies is one of the most significant technical challenges still ahead for PNGV.

Manufacturing Extension Partnership (MEP). Designed in the late 1980s, the MEP programme started to create a nation-wide network of Manufacturing Extension Centers in 1989 which now covers all states. Partnerships between the federal government, state/local governments and industry, these centres provide technical and business services to SMEs in order to improve their competitiveness. The range of services includes the introduction of environmental management and technologies and energy audits in addition to other services such as providing training and facilitating process and product improvement. The centres are created through a competitive, merit-based process where funding depends on successful annual review, and their operations are supported by contributions from public and private organisations that match federal funding. Although part of a national network, the centres are independent, non-profit organisations which offer services that meet the specific needs of the region's local manufacturers. Technical and business assistance is provided by MEP centre staff and outside consultants who are experienced manufacturing engineers and business specialists.

MEP centres often start by assessing a company's current operations and opportunities for improvement. Based on the assessment, MEP specialists recommend simple solutions or detailed plans of action. For firms requiring assistance in implementing these, the centre provides the solution and the support. For example, one centre, Texas Manufacturing Assistance Center, helped a wood products company to reduce their waste disposal costs by helping them find a way to recycle their waste wood and sawdust and turn them into products that could be sold. As a result, the company was able to save on waste removal costs and earn profits from the sale of recycled products. In cases in which the technical guidance needed by a firm is better found beyond the local MEP centre, the national network provides access to national partnership programmes of Federal agencies.

With respect to the effects of the programme, a US Census Bureau survey of over 2 000 firms served by MEP centres in 1996 showed that the firms did indeed increase sales and made substantial savings in inventory, labour and material. The companies attributed these benefits to MEP services. Another survey by the US General Accounting Office found that most firms using MEP assistance credited this for enabling them to improve productivity, product quality and profits.

EPA Partnership Programmes. The following are examples of partnership programmes to develop environmental technology associated with the EPA:

> ***National Industrial Competitiveness through Energy, Environment and Economics***. This is a joint DOE/EPA programme whose purpose is to advance industrial competitiveness through cleaner manufacturing processes. Grants are awarded to state/industry partnership projects that demonstrate and commercialise innovative processes and/or equipment to improve competitiveness, foster energy efficiency and prevent pollution in the manufacturing sector. Funds are given for three years during which awardees are to match federal funds with 55% cost sharing and agree to make the information on new processes public in order to maximise national spillovers and benefits.
>
> ***Green Chemistry***. Initially established in 1990, this EPA programme promotes pollution prevention and industrial ecology in partnership with the chemical industry through grants and awards and extensive outreach with industry and academia. Now part of the Design for the Environment programme, the scheme involves the design, manufacture and use of environmentally benign chemical products and processes that prevent pollution and reduce environmental and human health risks. It operates through a broad consortium of partners

including federal agencies, members of the chemical industry, trade associations, scientific organisations and representatives from academia.

Technology for Sustainable Environment. This EPA research and development grant programme is run with NSF to fund fundamental and applied research in physical sciences and engineering that would lead to the development of advanced and novel environmentally benign methods of industrial processing and manufacturing; it excludes waste monitoring and end-of-pipe technologies. The research areas specifically linked to pollution prevention for funding under this programme are chemistry, engineering, measurement and assessment and feedback engineering.

NSF Environmental Technology Programme. The Bioengineering and Environmental Systems Division of the National Science Foundation (NSF) has added a new element, Environmental Technology, to the Environmental Systems Program. It is directed towards supporting a portfolio of research in the area of pollution prevention and sustainable development technologies. While not explicitly a partnership programme, the NSF is seeking to encourage proposals that: *i)* cross engineering and science disciplinary boundaries; *ii)* provide a focal point of multidisciplinary review within NSF; and *iii)* facilitate co-operation with outside agencies and the private sector, particularly industries that are currently involved in environmental research in the form of co-operative research, use of equipment, loans of personnel or direct grants. The focus is on prevention rather than control. Research areas include:

– Industrial ecology, which aims to allow industry to adopt the cyclical laws of a natural ecosystem in order to incorporate environmental concerns into the design and manufacture of products and the processing of materials. Research may involve recycling, material recovery, disassembly, re-manufacturing, lifecycle analysis and pollution prevention.

– Pollution prevention, including non-point of source pollution prevention (“appropriate” technologies), water pollution prevention (waste water minimisation), air pollution prevention, environmentally benign process and/or production technologies.

– Sensors and new instrumentation to monitor environmental processes for improved control and faster feedback.

– Modelling which aids in avoiding or minimising pollution.

– Research leading to improvements in existing technologies to make them “greener”.

European Union

European Framework Programmes. In addition to programmes at the national level, the European Union maintains environmental and energy partnership projects within the overall Framework Programmes which started in the mid-1980s. Under the Third Framework Programme (1990-94), the stated objective of environmental research was to contribute to the scientific and technical basis for the implementation of EU policy in the areas of: *i)* global climate change; *ii)* technologies and engineering for the environment; *iii)* economic and social aspects of environmental issues; and *iv)* technical and natural risks. Some 554 projects were funded over the course of the programme, which had a project budget of ECU 300 million and an overall programme budget of ECU 315 million.

Under the Fourth Framework Programme (1994-98), the Environment and Climate Programme, with a budget of ECU 567 million, has had similar aims, among which are to: *i)* contribute to research into global change; *ii)* contribute to the cohesion and integration of European universities, research institutes and industry; *iii)* strengthen the European scientific base; *iv)* help develop the scientific knowledge and technical competence needed to fulfil environmental policy mandates; and *v)* contribute to growth, competitiveness and employment. To date, however, environment and climate research has primarily been directed to the geophysical sciences, including improved understanding of desertification, mechanisms of ozone depletion, human health risks from air pollution and effective use of Earth observation satellites. The contribution to the development of environmental technology relevant to improving industrial competitiveness and achieving broader economic goals has been limited. Under the Fourth Framework Programme, the Energy Programme has been directed more towards development of clean technologies, including those for the clean production and use of conventional energy sources.

In general, selection for participation in European Framework Programmes starts with a “call for proposals” published in the *Official Journal of the European Communities*. The scientific and technical appraisal of project proposals is carried out by groups of independent scientific and industrial experts, with approximately 50% of reviewers drawn from industry. Proposals are graded on three basic criteria: technical and scientific quality; innovative significance and economic exploitability of results; and value added by the performance of the work at a European level.

Participants are largely consortia, which may include both funded and non-funded members (*i.e.* those paying their own way), and any institution legally established in Europe, including universities and research institutes, may participate. As a general rule, projects should involve at least two non-affiliated firms or entities from two different member countries. There is a strong emphasis on promoting research co-operation among member states and creating pan-European innovative capacity. There are special provisions to stimulate participation by small firms. With regard to funding, there is a requirement for industrial matching funds. EU funding will not normally exceed 50% of the cost of a project, with progressively lower participation the nearer the project is to the market. Universities and other institutions that do not have analytical budget accountancy are reimbursed on the basis of 100% of additional costs.

In contrast to many other EU Framework Programmes, participation in the EU environmental research programmes has been dominated by universities and higher education and research institutes. Although strong emphasis is placed on collaborative projects with the private sector, less than 6% of participating organisations have been industrial firms. The environment and climate programmes have been partnerships or collaborative research ventures between universities and research institutes from different European countries. But for those areas of the programme more relevant for industrial involvement in the fields of environmental technologies, over 51% of projects funded involved an industrial participant and 29% involved at least one SME. The EU Five Year Assessment Report concluded that important contributions had been made to the development of environmental science and that progress was also made in forging a European research community via the formation of new research partnerships and networks. It further noted that signs were emerging of heightened industrial interest and that efforts would be made to increase industrial participation in the programme, especially by SMEs.

In the Fifth Framework Programme (1998-2002), the number of research programmes has been reduced and concentrated under four themes: *i)* quality of life and management of living resources; *ii)* creating a user-friendly information society; *iii)* promoting competitive and sustainable growth; and *iv)* preserving the ecosystem. The last has three subprogrammes: environment and sustainable development, energy, and Euratom activities. There is greater concentration on involving industry in these environment-related activities and on innovation. “Innovation units” are to be established within each of the programmes to provide support and advice to innovation-related aspects of programme management. A major challenge of the Fifth Framework Programme is to transform rapidly the outputs of projects into a format which can be targeted at and readily assimilated by policy makers and users such as the service sector and industrial enterprises.

THERMIE Programme. This programme is the demonstration component of the non-nuclear research and development programme JOULE-THERMIE. The current phase (1995-98) has a budget of ECU 577 million. Among other objectives, it aims to lower energy consumption and reduce the environmental impact of the production and use of energy, particularly CO_2 emissions. THERMIE also aims to contribute to realising other EU objectives such as reinforcing the competitiveness of EU industry (especially SMEs) with benefits for the economy, employment and export potential. The programme provides financial support on a shared-cost basis for demonstration projects that implement innovative energy technologies for the rational use of energy, renewable energies and fossil fuels, including clean technologies for solid fuels. Community support covers a maximum of 40% of the total eligible cost of the projects. Proposals for projects must come from a consortium of at least two non-affiliated legal entities from different member states.

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GOVERNMENT PROGRAMMES FOR DIFFUSING ENVIRONMENTAL TECHNOLOGIES

SUMMARY

Technology holds the key to addressing many environmental problems and achieving sustainable patterns of economic growth. In many cases, the appropriate technological solution already exists. However, the technology may not be in widespread use because of its price, the lack of information on the part of firms or other market failures. Technology diffusion is essential to realising sustainable development goals. To this end, OECD governments are now implementing innovative schemes to disseminate information about environmental technologies and to promote enhanced use of these techniques among a greater number of enterprises, both large and small. An important aspect of these programmes is informing firms of the benefits of environmental technologies in terms of efficiency, performance, profits and longer-term competitiveness.

There are many types of environmental technology diffusion programmes and services on offer. Providing information is at the core of all diffusion programmes and this is increasingly being done through electronic networks such as the Internet. Also prominent are demonstration programmes, which illustrate the technical feasibility and benefits of new environmental technologies, and benchmarking schemes, which help firms compare their environmental performance to that of similar enterprises. Technical assistance programmes provide more hands-on advice in diagnosing environmental problems and finding the appropriate technological solutions. Governments are increasingly mounting "soft" diffusion activities which focus on workforce training and encouraging managerial and organisational changes within firms to improve their ability to assess and adapt environmental technologies. Lastly, financial assistance is often provided in differing degrees to facilitate industry adoption of new environmental approaches.

Some technology diffusion approaches and schemes seem to work better than others in terms of disseminating technologies and improving the environmental performance of firms:

Giving effective incentives – Environmental regulations and other well-designed policy instruments are generally the most effective incentive to the adoption of new technology; however, direct and indirect financial incentives can also be key for changing technologies.

Promoting clean technologies – Diffusion programmes should be focused on disseminating clean technologies, which entail changes in processes and products, rather than add-on or end-of-pipe techniques.

Targeting sectors and problems – The most effective technology diffusion programmes tend to target specific industrial sectors and/or certain types of environmental problems identified through audits.

Orienting programmes locally – Diffusion programmes should have the ability to reach and interact with enterprises as close to home as possible, with the best programmes incorporating both local and national elements.

Providing integrated services – The integration of information sources and technology diffusion services into a broad co-operating network facilitates ease of access for users.

INTRODUCTION

Many countries have established programmes to promote broad diffusion of environmental technologies to business and industry. Government programmes to diffuse environmental technologies may be considered a subset of more general technology diffusion programmes that help firms identify, absorb and implement technology and know-how. The rationale for government programmes for promoting *general* technology diffusion also apply to diffusion of environmental technologies (OECD, 1997*a*). First, these schemes may be intended to address *market failures;* firms may lack information about technologies or face disadvantages due to scale requirements, lack of financial resources or high learning costs, resulting in underinvestment in new technologies. Or they may be addressed to *systemic failures*, which arise from weaknesses in linkages and interactions among firms, universities, public research institutes and others involved in developing, supplying and using technology.

The overarching objective of programmes to diffuse environmental technologies is to help firms prevent or reduce the impacts of their activities on the environment. As environmental technologies are developed and put into use, the adverse effects of economic activity on the environment and human health can be considerably reduced relative to what they would have been in the absence of such technologies. Many opportunities exist in most industries to minimise waste and reduce pollution of air, water and land through the use of better technology and management practices. At the global level, concerns such as climate change or reduction in biodiversity can be at least partially addressed through the greater use of "environmentally-friendly" technologies and practices (OECD, 1997*b*).

Although many new technologies needed to meet sustainable development goals remain undeveloped, technical solutions to a large share of the environmental problems in manufacturing and services sectors already exist. They just need to be diffused more widely among firms. Of course, the most effective means of prompting enterprises to adopt new technology is through regulations and financial incentives. However, an integral part of the broader diffusion effort is also informing and convincing firms of the benefits of environmental technologies in terms of efficiency, performance and profits. Many programmes to promote diffusion of environmental technologies suggest ways to cut costs and increase earnings by improving efficiency and minimising waste. Environmental technologies do not necessarily cost more, and they may often lead to reduced investments in materials, conserved energy and improved competitiveness.

In particular, programmes to diffuse environmental technologies to small and medium-sized enterprises (SMEs) make sense because, by necessity, management of most SMEs in the manufacturing sector is directed toward the primary processes of producing and selling products (OECD, 1992). Such firms tend to concentrate on the short-term; environmental problems and their solutions are usually viewed as long-term. As a result, potential opportunities for cost savings, developing new products and markets, etc. often receive low priority and little attention. Smaller companies, moreover, often do not have staff with sufficient environmental knowledge or expertise to be able to address problems and opportunities in the environmental field. In recognition of these problems, technology diffusion schemes – environmental and other – are increasingly aimed at improving the managerial and organisational abilities of smaller firms, including the capacity to identify, assess and adapt new technologies on a continuing basis (OECD, 1997*a*).

TYPOLOGY OF PROGRAMMES

Most OECD countries have programmes or schemes whose aim is to accelerate the rate of diffusion of environmental technologies. In order to facilitate analysis and comparison, the types of services offered by these programmes can be divided into information services, demonstration programmes, benchmarking, technical assistance, management assistance, workforce training and financial assistance (see **Table 1**). Below, some of the most interesting examples of the different types of programmes implemented by the OECD countries sampled in this report are presented. More detail on each of these programmes is given in the **Annex**.

Table 1. Typology of diffusion programmes

PROGRAMME TYPE	PURPOSE	EXAMPLE
Information services	To disseminate information on the best environmental technologies, processes and management practices.	**United Kingdom** – *Environmental Technology Best Practice Programme*
Demonstration programmes	To illustrate the benefits of new environmental technologies or to verify their technical feasibility.	**Australia** – *Cleaner Production Demonstration Project* **Canada –** *Environmental Technology Verification programme*
Benchmarking	To help enterprises compare how well they are doing relative to other enterprises in the same sector.	**United Kingdom –** *Energy Consumption Guides*
Technical assistance	To assist firms in diagnosing technology needs, problem-solving and implementing new environmental approaches.	**Ireland** – *Environmental Audit Grant Scheme* **United States** – *Design for the Environment* and *Green Lights Programmes*
Management assistance	To improve managerial and organisational skills in identifying and adapting new technology.	**Canada** – *Canadian Environmental Technology Advancement Centres* **France** – *ADEME*
Workforce training	To upgrade staff skills in using new technologies and support hiring of environmental specialists.	**Netherlands** – *IMPRES* **Denmark** – *SME Programme*
Financial assistance	To support implementation or development of new technologies or management practices.	**Denmark** – *SME Programme* **United Kingdom** – *Future Practice Programme* **United States** – *Innovative Concepts Programme*

Source: OECD.

Information services

Providing information is at the core of all environmental technology diffusion programmes. Often it is the principal aim of such programmes, but even where other technology diffusion services (e.g. technical assistance) are emphasised, information dissemination is always involved. The OECD countries surveyed use a variety of different means to disseminate information, but the one means common to all is through dissemination of the written word. This is done chiefly through publication and distribution of manuals, guidebooks, case studies and other written materials, most often tailored for the needs of specific sectors or industries. Often, the intent is not just to disseminate information on the existence or availability of environmental technologies, but also to illustrate that these technologies can be cost-effective and improve efficiency and profitability as well as environmental performance.

The availability of information may be advertised at trade shows or in trade journals or newsletters, but other effective techniques have been used as well. Electronic means are becoming increasingly popular. At least one country, the Netherlands, has produced a televised education course on cleaner production for entrepreneurs. France has disseminated information on environmental technologies through the Minitel. Many countries now disseminate information through the Internet, for example, Australia with its *Environmental Technologies Case Studies Directory* and the United States with its *Design for the Environment* web site. A list of relevant web sites is given in **Box 1**.

Many governments also organise small workshops and training sessions on specialised topics. For example, the *Clean Technology Centre* in Ireland offers training sessions on waste minimisation and environmental management. On a larger scale, France’s *Agence de l’Environnement et de la Maîtrise de l’Énergie* (ADEME) is a co-sponsor of an annual conference and exhibition on energy efficiency and clean technologies that draws up to 40 000 people. The United Kingdom’s *Environmental Technology Best Practice Programme* (ETBPP) helps facilitate waste minimisation clubs – groups of companies with similar problems that get together to exchange information on technologies, methods and management practices used to minimise waste and improve environmental performance.

The parallel ETBPP and the *Energy Efficiency Best Practice Programme* (EEBPP) of the United Kingdom illustrate typical features of programmes designed to provide information. Both programmes publish information by way of “Good Practice Guides” and Case Studies. Those of the ETBPP provide examples of proven, cost effective measures that have improved environmental performance. They often contain information on how good practices can be profitable. Likewise, the energy efficiency guides produced by the EEBPP give information about best practices currently associated with energy use in a particular industry. The types of material provided may include information on specific energy efficient technologies, design considerations, management techniques, operating practices, education and training and staff motivation. Case studies complement the guides in both programmes and offer concise, specific examples of proven energy efficiency measures. The guides are usually free of charge. These same two programmes also produce what are known as “New Practice Case Studies”. These monitor and promote new environmental technologies or energy efficiency measures and evaluate their benefits so as to increase awareness and stimulate the confidence that will lead to adoption of environmental technology in specific industrial sectors.

A somewhat different approach is taken by France’s ADEME, which selects a different theme to emphasise each year. In 1996, for example, the accent was on waste problems and atmospheric pollution. In its information programme, ADEME publishes a broad range of practical guides written for the needs of enterprises. Generally, ADEME’s guides are inexpensive but not free. A recent catalogue lists some 90 different guides. One example is a guide to reducing industrial emissions of volatile organic compounds. This guide, typical of those available, provides an inventory of technologies for reducing these emissions and concrete examples of how to apply the technologies.

Box 1. Web sites for diffusion of environmental technology

Australia

- *EnviroNET*: http://www.environment.gov.au/net/environet.html
  Environmental Technology Case Studies Directory:
  http://www.environment.gov.au/portfolio/epg/environet/rsd/rsd.html
  Cleaner Production Case Studies Directory:
  http://www.environment.gov.au/portfolio/epg/environet/ncpd/ncpd.html:

Austria

- *Austrian Environmental Technologies Database*: http://www.umwelttechnik.at
- *Austrian EcoDesign Infopoint*: htt://www.ecodesign.at/ecodesign/

Canada

- Environment Canada:
  Environmental Technology Advancement: http://www.doe.ca/etad
- Industry Canada
  Canadian Business Environmental Performance Office: http://virtualoffice.ic.gc.ca/bepo/
- Canadian Environmental Technology Advancement Centres
  CETAC-WEST: http//www.cetacwest.com
  Ontario Centre for Environmental Technology Advancement: http://www.oceta.on.ca/
  Enviro-Access: http://www.enviroaccess.ca
- *Services and Information on Ecotechnologies: http://www.sie.org/*

France

- *Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME)*: http://www.ademe.fr/

Ireland

- *Clean Technology Centre (CTC)*: http://www.rtc-ork.ie/rd/cleant/CleanTech/NETBACKU/Clean4.htm

Norway

- *GRIP Centre for Sustainable Production and Consumption:* http://home.sol.no/~martins/grip001.htm

United Kingdom

- *Environmental Technology Best Practice Programme (ETBPP)*: http://www.etsu.com/ETBPP/index.html
- *Energy Efficiency Best Practice Programme (EEBPP)*: http://www.etsu.com/eebpp/home.htm

United States

- Environmental Protection Agency (EPA): http://www.epa.gov/
  Design for the Environment: http://www.epa.gov/dfe/
  Environmental Technology Initiative: http://www.epa.gov/oppe/eti/eti.html
  Hazardous Waste Clean-Up Information: http://clu-in.com/
  Pollution Prevention Directory: http://www.epa.gov/opptintr/ChemLibPPD/
  Reinvention for Innovative Technologies (ReFIT): http://www.wpi.org/epa/refit/
  Small Business Compliance Assistance Centers: http://es.epa.gov/oeca/mfcac.html
- Department of Energy (DOE):
  Environmental Management, Office of Science & Technology: http://em-50.em.doe.gov/

The Dutch *Cleaner Production Programme* (CCP) is focused on disseminating information to SMEs about cleaner production and is organised around a four-tiered communication model. The national communication tier emphasises information dissemination through the mass media, trade journals and data banks. The regional information tier focuses on information meetings and training courses. Activities related to trade and industrial organisations focus on training, publication of manuals and fact sheets, and discussion platforms. And the individual advice tier provides consultancy services to individual companies.

Evaluations of this programme have highlighted its success in diffusing environmental technology to smaller firms and have prompted the renewal of the programme for at least an additional three years.

Demonstration programmes

Two distinctive types of demonstration programmes have been used by one or more of the ten OECD countries reviewed. The first, illustrated by the programmes of Denmark, Norway and Australia, focuses on showing how adoption of innovative technologies, processes or management tools can lead to reduced waste, environmental impacts and/or cost. Thus, the goal of the "recycled house" project in Denmark was to erect a new building as part of an urban renovation project in Copenhagen using as much recycled construction material as possible. The project demonstrated how to reduce waste, which in turn led to a reduced need for landfilling, raw materials, energy and materials transport. As part of the project, a handbook was produced which described control procedures that must be employed when selecting recyclable materials. Norway's *GRIP Centre for Sustainable Production and Consumption* conducted a pilot project to demonstrate that selective demolition with material sorting can more than halve waste volume without increasing costs above those normally incurred.

More ambitiously, Environment Australia (EA) has used external consultants to demonstrate the benefits of cleaner production. The goals of EA's *Cleaner Production Demonstration Project* (CPDP) were to raise the environmental awareness of Australian industry and actively promote implementation of cleaner production technologies and processes. To achieve this goal, EA hired the Dames and Moore consulting firm and asked this company to assist companies participating in the programme to identify and implement cleaner production practices. Specifically, the consultant was asked to identify ten companies that would be willing to give cleaner production practices a try, commit resources to the project and let their cleaner production initiatives be publicised. The consultancy lasted a little over two years, during which the companies worked directly with the consultant on site to identify and implement cleaner production opportunities. Once the projects were completed, EA asked Dames and Moore to write a "how to" manual on cleaner production using the project companies as examples. Newsletters, a promotional brochure and a video were also produced to document the experiences and benefits achieved by each company and to publicise the results widely.

A second Australian demonstration project funded by EA had a slightly different goal. The purpose of the *EcoReDesign* project was to demonstrate how ecodesign can reduce the environmental impacts of producing, using and disposing products and how innovative environmental technology can help business capture domestic and international markets. Following a nationwide search, six different types of small enterprises were selected to participate. With the help of design and environmental consultants provided by the Royal Melbourne Institute of Technology (RMIT), these six companies redesigned their products. Some of the participating companies have begun marketing their new products; others plan to do so in the near future. RMIT has documented the processes and products involved in the project and has recently produced an EcoReDesign Kit (including a video, case study materials, a step-by-step guide and a resource directory) to help other manufacturers, designers and engineers interested in ecodesign.

Canada's Environmental Technology Verification (ETV) programme represents a second type of programme whose main purpose is to demonstrate the feasibility of new environmental technologies at the pilot project or pre-commercial stage and to work with private and public sector partners to promote the application and transfer of such technologies. The ETV programme is designed to provide validation and independent verification and performance claims for environmental technologies and equipment-based services. To be eligible for the ETV programme, the technology must be an environmental technology or service whose performance can be verified; offer an environmental benefit or address an environmental problem; meet minimum Canadian standards and/or national guidelines for the technology type; and be currently commercially available or ready for full-scale operation. Verification certificates are awarded to successful applicants, and these can be of considerable value in facilitating the diffusion of the technology.

Benchmarking

Benchmarking refers to the collection and dissemination of environmental and resource use information that allows enterprises in a given sector to compare how well they are doing relative to other enterprises in the same sector. By making this information available in conjunction with suggestions to help reduce costs and optimise processes, enterprises with inferior practices and/or higher costs can adopt improved practices and become more competitive. For example, the United Kingdom's ETBPP produces a series of environmental performance guides. One such guide details the main findings of a survey of 105 UK foundries that use chemically-bonded sand. Various statistics are presented that allow individual foundries to compare how well they are doing (e.g. in amount of sand used to castings produced) relative to the average for the industry and to those with the best performance. The guide also contains a Sand Action Plan, which includes suggestions to help companies reduce sand costs and use and to optimise the disposal and/or reclamation of used sand.

Similarly, the United Kingdom's EEBPP provides data on how energy is currently used within particular industrial sectors and for different processes or building types, allowing organisations to compare their own energy usage with that of others in equivalent organisations. Each guide contains an Action Plan of achievable energy-saving measures to encourage organisations to take the appropriate first steps toward becoming more efficient. Guides may be promoted through workshops and seminars, targeted mailings or articles in the technical press.

Technical assistance

Like information services programmes, the central aim of technical assistance programmes is to provide information. However, technical assistance goes beyond relatively passive dissemination of information via published materials and focuses on active, face-to-face information transmittal. The Australian and Canadian technology demonstration programmes noted above are good examples of technical assistance, but the OECD countries sampled employ many other types of technical assistance programmes that have successfully promoted the diffusion of environmental technologies.

One common technical assistance programme is the environmental audit. These are often provided at subsidised rates. For example, in the Netherlands, small firms are eligible for what are known as "environmental scans". Two types are available: the Dutch Regional Industrial Environment Agencies provide assistance on regulatory and licensing issues while the regional Innovation Centres focus on technology issues. The product of a scan is a report that outlines the environmental risks faced by the "scanned" company and a list of options for improvement. A similar programme is offered to UK companies. The ETBPP provides an environmental counsellor – free to smaller firms – to conduct half-day site visits. The counsellor provides technical advice on best environmental practices and follows up the visit with a report containing suggestions for improvements. The ETBPP, as well as several other programmes, also provides an environmental helpline to which queries related to environmental technology, legislation and other issues may be directed.

In Ireland, the *Environmental Audit Grant Scheme* (EAGS) has been established to stimulate and support smaller firms to improve their environmental performance without hurting profits. Qualifying SMEs are granted up to 50% of the costs (up to a maximum of IEP 5 000) of conducting an audit. Among other things, the programme has helped businesses identify cost savings through implementation of waste minimisation practices, plan investment programmes to meet higher environmental standards in the most cost effective manner, and prepare for Integrated Pollution Control Licensing and the setting up of Environmental Management Systems.

In south-eastern Germany, the *Bavarian Environmental and Consulting Programme* provides consultants at subsidised rates to undertake the analyses or audits of SMEs. The basic subsidy for SMEs (defined as enterprises having a turnover of under DEM 30 million) is 80% of total costs up to a maximum of DEM 30 000. Subsidies that vary depending on the turnover and/or size of the SME are also available to provide assistance in implementing the International Organization for Standardization's environmental management system standard.

Technical assistance, however, extends well beyond relatively simple environmental audits. The *Clean Technology Centre* in Ireland, for example, operates a process engineering consultancy service which includes desktop studies, eco-design of products and technology transfer assistance. The *Design for the Environment Programme* in the United States has developed a variety of analytical tools for use by business. One is a generic assessment procedure that will help companies conduct their own in-house assessments. A second is a method to help companies evaluate the environmental effects of a product, process or activity throughout its life-cycle (from raw material extraction and production through final disposal). A third, which is being done with the assistance of the private sector, is to develop new and modified accounting tools to help enterprises incorporate environmental costs and benefits into managerial accounting and capital budgeting practices.

The *Green Lights Programme,* managed by the US Environmental Protection Agency (EPA), is a successful public-private partnership that combines technical support and information provision. EPA promotes energy-efficient lighting by asking major institutions to sign a memorandum of understanding with the Agency. Each signatory institution commits to install energy-efficient lighting in 90% of its space nationwide over a five-year period, but only where it is profitable and where lighting quality is maintained or improved. EPA, in turn, offers programme participants a number of technical support services to assist them in upgrading their buildings. For example, a computerised decision support system developed by EPA provides Green Lights corporations and governments a rapid way to survey the lighting systems in their facilities, assess retrofit options and select the best energy-efficient lighting upgrades.

Management assistance

The concept of technology diffusion has been evolving, initially from one dealing with the simple transfer of technology embodied in equipment to one including all those actions at the level of the firm taken to exploit the benefits of technology. Among these, in addition to the introduction of new equipment or processes, are such "soft" diffusion activities as organisational changes to production and improvements in management practices, training and networking (OECD, 1997*a*).

Some technology diffusion programmes focus specifically on upgrading management skills in identifying and adapting appropriate environmental technologies. France's ADEME, for example, promotes environmental management through its *Enterprise Environment Plan*. This plan has been jointly developed with the Ministry of Industry and the Ministry of the Environment to help enterprises improve their energy and environmental management and to enable them to qualify for ISO 14001 certification or to pass an eco-audit. This plan is intended especially for smaller firms. Implementation of the plan allows firms to reduce energy consumption and waste production and to limit discharges of pollutants at an economically acceptable cost. Two documents have been produced, one intended for enterprise heads that discusses how to initiate and track environmental management, the second for key environmental personnel which gives recommendations and suggests practical steps to take to implement the plan. Similarly, Ireland's *Clean Technology Centre* assists companies in designing and implementing environmental management systems.

Canadian Environmental Technology Advancement Centres, or CETACs, aim to help SMEs commercialise environmental technologies by providing a wide range of services: assistance in accessing investment capital, general business development counselling, technical and legal services, market analysis and strategic advisory services. By making information on these technologies widely available, the CETACs contribute to their diffusion. One of the CETACs, the Ontario Centre for Environmental Technology Advancement, or OCETA, is playing a key role in the establishment of Services and Information on Ecotechnologies (SIE), which provides an electronic information service intended to assist waste generators in making environmentally and economically sound choices.

Workforce training

A number of programmes offer training for employees. Representative programmes include the *IMPRES* project in the Netherlands. This is an example of collaboration between trade and industrial organisations and the National Environmental Centre. One of the elements of this programme is training tailored for each industrial sector targeted. Similarly, the *Clean Technology Centre* in Ireland and the French *ADEME* provide training to companies on such topics as waste minimisation, environmental management and safety. It is noteworthy that the *Clean Technology Centre* is based at the Cork Regional Technical College and has strong links with this technical educational institute.

The Danish SME programme is unusual in that it subsidises not only some staff training but also costs for hiring new employees engaged in environmental work. Important objectives of this programme are to improve the environmental awareness of existing staff members; to strengthen co-operation and networking among enterprises, local authorities, training programmes and consultants; and to increase the sales of environmental products, systems and services. To accomplish these objectives, the Danish government budgeted DKK 80 million through 1997. The programme funds up to 50% of the costs of a project of an SME or group of SMEs up to a limit of DKK 400 000. Covered costs may include costs for new employees engaged in environmental work, internal wages for project activities, expenses for development and testing of new environmental technologies or processes, staff training, and, in part, costs of external consultants.

To qualify for support under the Danish SME programme, projects must execute one or more improvement projects; establish an environmental policy, targets and action plan; involve staff in planning and implementation; and hire new staff with environmental expertise. Programme results to date show that the hiring of additional skilled staff was one of the most important factors in successful projects, and more than 80% of new staff stayed in their jobs after the completion of the project. Many enterprises stressed the importance of the compulsory elements of the programme, the systematic approach required and the involvement and training of existing employees.

Financial assistance

Subsidies, grants and other forms of financial assistance are used to some extent by all of the countries surveyed for promoting the diffusion of environmental technologies. Direct and indirect financial assistance is often essential to prompting firms to adopt new technologies which may require significant investments and whose performance may be untested. In general, companies will adopt new technologies if they have fully recuperated the investment made in their existing technology and if the cost to change processes is less than continuing with those in place, even if they incur more operating and feedstock costs. Government financial assistance is one way of shortening the investment life cycle of capital investments in new technology.

One common type of monetary assistance, noted above and typically given to SMEs, is for an environmental audit. Thus, for example, Ireland has its *Environmental Audit Grant Scheme*, wherein up to 50% of the costs of conducting an audit are covered with Irish government and European Union funds. Germany's *Bavarian Environmental and Consulting Programme* subsidises 80% of total costs (up to a maximum of DEM 30 000) to undertake audits. In both cases, the programmes help businesses identify cost savings through implementation of waste minimisation practices, plan investment programmes to meet higher environmental standards in the most cost effective manner, and prepare for setting up of environmental management systems and certification under the European Union's voluntary *Eco-Management and Auditing Scheme*.

Another type of support for SMEs is that given by Denmark. The objectives of the assistance are to increase the number of SMEs with environmental policies and action plans; to improve the environmental, health and safety performance of SMEs; to increase investments in cleaner technology and energy saving equipment; to improve the environmental awareness of existing staff members; and to increase the sales of environmental products, systems and services. The programme funds up to 50% of the costs of a project of an SME or group of SMEs up to a limit of DKK 400 000. Covered costs may include those for new employees engaged in environmental work, internal wages for project activities, expenses for development and testing of new environmental technologies or processes, staff training and, in part, costs of external consultants. Individual projects cover a wide variety of activities, from product and process development, to improvements in resource management systems. Thus far, more than 200 different SME projects have been implemented.

Support programmes in the United Kingdom and France are specifically directed toward promoting innovation. In the United Kingdom, the Future Practice elements within both the ETBPP and EEBPP provide financial support for research. The ETBPP and the EEBPP provide up to 49% funding for appropriate multi-client projects. ADEME applies part of the special environmental taxes it collects to support technology development. In the Netherlands, one financial incentive scheme allows entrepreneurs the opportunity to depreciate investments in certain environmental measures or facilities faster than would normally be the case.

The *Innovative Concepts Programme*, also in the United States, provides seed-money grants to encourage energy innovation and help new technologies move more quickly from the conceptual state into the marketplace. The programme seeks to be the "first funder" for concept-stage technology in specific problem areas, such as waste minimisation and utilisation. The seed funding is intended to fund concept definition to a stage at which other prospective sponsors can more clearly assess the potential of the concept.

Indirect financial incentives – particularly tax measures – are also being used to promote the take-up of new environmental technologies. Examples of fiscal incentives include the Netherlands scheme which allows accelerated depreciation of investments made in certain environmental measures or facilities; a 20% tax credit given in the Canadian province of Quebec for environmental technology investments; and the proposed USD 500 billion tax credit programme in the United States to prompt the development and use of energy efficiency technology to curb greenhouse gas emissions. Investment instruments and venture capital schemes may be employed to environmental ends, although this is not yet widespread. In Denmark, efforts are being mounted to link financial institutions managing environmental investment funds to the appropriate firms. Similarly, Norway is funding a prize for the company that provides the best environmental information to the financial and investment community.

Promotion of environmental technology diffusion through prizes for achievements is practised in several countries. France's ADEME, for example, promotes technology diffusion through an annual "*Clean and Efficient Technology*" prize. The prize is given to recognise industrial enterprises that have rethought fabrication processes and have been able economically to substitute polluting compounds, develop clean processes, recycle or put waste with high energy potential to use. Since 1993, 20 enterprises, both large and small, have been awarded prizes.

CONCLUSIONS

The countries and programmes reviewed in this report provide many examples of effective means of diffusing environmental technologies to business and industry. Some tentative conclusions about what makes for good practice, based on the representative examples in the report, are discussed below. Often, the quantitative data that would allow one to judge the success of a programme or to better compare one programme with another are either inadequate or unavailable. It may also be the case that something that works well in one country or institutional setting will not transfer well to another country. Nevertheless, some general conclusions may be drawn about the diffusion practices that produce results and that could be effectively emulated.

Giving effective incentives – An important, if not essential, part of promoting diffusion of environmental technologies is to give incentives to firms to adopt new techniques whose benefits may not be readily apparent. Environmental regulations, particularly product and performance standards, and other policy instruments, such as economic instruments and approaches like extended producer responsibility, can be the most effective incentives to the adoption of new technology. Government laws and policies, when flexible and well-designed, can encourage changes towards clean technology in manufacturing practices and service sectors. In general, governments should develop and enforce environmental policy approaches that stimulate innovation in industry; that encourage development and deployment of new technologies; that provide economic incentives for the use of clean technologies; and that are integrated with technology policies to ensure adequate R&D funding for development of environmentally superior technologies (OECD, 1997*c*).

Since the cost and unproven performance of new environmental technologies are often the greatest barrier to diffusion, direct and indirect financial incentives are no doubt the next most effective means of encouraging their adoption. All countries provide such assistance to some extent. For example, in Denmark, up to 50% of the costs of small firms to develop environmental action plans and invest in cleaner technologies are paid by the government. One US programme provides seed money to help new technologies move more quickly from the conceptual stage to market, while the United Kingdom gives up to 49% funding for projects to promote energy efficiency. Countries are also increasingly employing fiscal incentives such as accelerated depreciation and tax credits for industry investments made in environmental technologies. Newer approaches could target private and public venture capital funds and other investment instruments towards environmental technology investments.

Promoting clean technologies – Programmes to diffuse environmental technologies should be focused on disseminating *clean technologies,* which offer the most far-reaching benefits in terms of improving eco-efficiency. Cleaner, more efficient production is the goal of these technologies, as opposed to the more limited and short-term improvements yielded by add-on or end-of-pipe techniques. Clean technologies are generally intended to reduce or prevent the generation of waste and pollution, eliminate or render less harmful existing waste and pollution, use energy more efficiently or reduce raw material consumption. Some prominent examples of clean technologies include separation technologies used to recover valuable substances and allow re-use of liquids; biological methods for treating wastes and recovering useful material; closed-loop systems that produce no air emissions, solid wastes or effluent discharges; process control technologies that ensure product quality and process efficiency; and techniques that use alternative substances, such as supercritical fluids instead of solvents, or renewable or lower-polluting forms of energy.

Targeting sectors and problems – The most effective technology diffusion programmes tend to target specific industrial sectors and/or certain types of environmental problems. In general, information and services tailored to the specific needs of individual sectors are more useful than general information provided to multiple industrial and business fields. The intent is to increase awareness and stimulate the confidence that will lead firms to adopt cleaner technologies; this propaganda element seems to work best when diffusion schemes are problem or sector specific. Thus, in most cases, programmes promoting cleaner production are managed separately from programmes promoting energy efficiency. Some schemes target groups of companies of similar size with similar problems, such as the waste minimisation clubs in the United Kingdom. Other programmes emphasise a different sector or ecological problem each year. In addition, many environmental problems are plant-specific, underlining the importance of environmental audits to pinpoint particular problems and technical solutions.

Orienting programmes locally – Another aspect of providing information and other types of technology support is the ability to reach and interact with enterprises as close to home as possible. This is the rationale behind, for example, the Regional Innovation Centres in the Netherlands and the regional ADEME offices in France. Being involved locally helps information and service providers become more familiar with special local problems and needs; ecological characteristics and choices may differ greatly according to geographical region. It also makes follow-up on the initial contact with a firm more practical. Smaller firms, in particular, may benefit from the local availability of information and the link to service providers. This also facilitates the use of intermediaries such as local research institutes and trade associations, who can prove invaluable to disseminating technology. Overall, the most effective technology diffusion programmes seem to be those that comprise both local and national elements, thereby benefiting from closer contacts with firms and the financial and technical resources which may be available nationally.

Providing integrated services – The integration of information sources and technology diffusion services into a broad co-operating network is the best overall approach. Integration facilitates ease of access to the different types of assistance that may be available, including information dissemination, technology demonstration and technical supports. The range of services should also give sufficient attention to training workers and upgrading the innovative capacity of firms; this includes promoting general awareness of the value of environmental technologies among management and stimulating demand for technical and related organisational change within firms. An integrated approach can not only benefit enterprises directly but help the collaborating organisations in the programme improve co-operation with each other, producing further benefits. Perhaps the most closely integrated network is that of the Netherlands Cleaner Production Programme, which promotes communication and links information sources through four different channels (national schemes, regional institutes, industry associations and individual enterprises). In all countries, there is a need for improved alliances between technology promoters and public-sector and industrial users; technology diffusion programmes can benefit from strong links with universities and technical institutes.

ANNEX: OECD COUNTRY PROGRAMMES

Australia

Environment Australia (EA), in partnership with industry and local and regional government agencies, has implemented a number of activities for diffusing environmental technologies to business and industry. Among these are the Cleaner Production Demonstration Project, the EcoReDesign project and the Cleaner Production Partnership Project. Environment Australia also provides information about cleaner production and environmental technologies in several Internet-accessible databases. The *Environmental Technologies Case Studies Directory* and the *Cleaner Production Case Studies Directory* are organised in similar fashion. Each defines a problem, discusses a solution and provides information on the case study site, the nature and performance characteristics of the technology, additional technical details, capital and operating costs, suppliers and contacts. Booklets are also available.

Cleaner Production Demonstration Project. The goals of the Cleaner Production Demonstration Project (CPDP) are to raise the environmental awareness of Australian industry and actively promote implementation of cleaner production technologies and processes. To achieve this goal, EA hired an external technical consultant, Dames and Moore, and asked this company to assist participating companies in identifying and implementing cleaner production practices. Specifically, the consultant was asked to identify ten companies that would be willing to give cleaner production practices a try, commit resources to the project and let their cleaner production initiatives be publicised. The consultancy lasted a little over two years, during which the companies worked directly with the consultant on site to identify and implement cleaner production opportunities. Once the projects were completed, EA contracted with Dames and Moore to write a “how to” manual on cleaner production using the project companies as examples. Newsletters, a promotional brochure, and a video were also produced to document the experiences and benefits achieved by each company and to publicise the results widely. Summaries of the demonstration projects may be accessed via the Internet.

Nowra Chemical Manufacturers was selected as one of the ten participating companies in the CPDP. The focus of this project was to determine how to reduce waste sludge resulting from the chemical manufacturing process. The approach involved: *1)* an initial site visit conducted by the technical consultants, in association with Nowra; *2)* follow-up site visits and meetings to review site processes in detail and to identify specific cleaner production opportunities; *3)* evaluation of benefits and costs associated with each potential opportunity; *4)* selection and implementation of the project; and *5)* follow-up monitoring to demonstrate project benefits. Through this process, it was determined that Nowra could separate effluent steams that had previously been combined, a change that led to much less waste sludge. By making process modifications and employing new technology, and subsequently monitoring the results, Nowra was able to cut its production of sludge by 66%, thus decreasing the amount of sludge disposed in landfills by 16.5 tonnes per year and the quantity of wastewater produced by 832 kL per year. According to a post-project review, the project demonstrated that cleaner production can be applied to a small firm (Nowra employs only 34 people) and that, in some cases, the availability of outside technical expertise can make an important difference.

EcoReDesign Project. The EcoReDesign Project is another type of demonstration project implemented in Australia. Funded by the EA and co-ordinated by the Centre for Design at the Royal Melbourne Institute of Technology (RMIT), the objectives of this project were to demonstrate how ecodesign can reduce the environmental impacts of producing, using and disposing products and how innovative environmental technology can help business capture domestic and international markets. Following a nationwide search, six different types of small enterprises were selected to participate. With the help of design and environmental consultants provided by RMIT, these six companies redesigned their products. Some of the participating companies have begun marketing their new products; others plan to do so in the near future. RMIT has documented the processes and products involved in the project and has recently produced an EcoReDesign Kit (including a video, case study materials, a step-by-step guide and a resource directory) to help other manufacturers, designers and engineers interested in ecodesign.

Cleaner Production Partnership Project. The Cleaner Production Partnership Project is a new regional project to build strategic partnerships between large companies and SMEs. The new Victoria programme will broker industrial partnerships between major companies and their upstream and downstream stakeholders. Thus, it is intended that experienced managers from mentor companies will be seconded to SME partners for 3 to 6 months to facilitate the transfer of “know-how”. The goal is to create a core of best practice small companies that will become models for their industry sectors.

Austria

Austria has mounted a comprehensive approach to diffusing environmental technologies to firms of all sizes in a range of industrial sectors. A number of interlinked programmes, networks and databases are joined under the umbrella of the *Austrian National Cleaner Production Activities* programme to form an institutionalised information platform for developing and disseminating sustainable technologies.

Austrian Cleaner Production Centre. The Austrian Cleaner Production Centre serves to transmit information on technological developments and cleaner production research to government bodies, researchers, consultants and industry. Among its activities, it stimulates research and innovation on environmental technology through disseminating research findings and organises a forum for the exchange of experiences with clean production techniques. It also supports demonstration programmes, training programmes and an electronic *Info-Trading-Centre* on the Internet which fosters discussions on cleaner production and spreads information on research, successful implementation and technological trends. This Centre is supplemented by a number of regional and local cleaner production programmes.

EcoDesign. Design for the environment or ecodesign features prominently in the Austrian approach to environmental technology diffusion. The EcoDesign Infopoint is an electronic network established to promote design for cleaner production and sustainable products within Austria. It provides a platform for exchanging ideas and information on ecodesign as well as a gateway for international agents to locate Austrian researchers, companies and organisations working on ecodesign. In addition, a series of “Train the Trainers Workshops” on ecodesign have been organised.

Austrian Network on Technologies for Sustainable Development (ATSD). This network has recently been established by the Austrian Ministry of Science and Transport to support and fund the development and diffusion of technologies for: efficient energy consumption, renewable energy sources, renewable raw materials, cleaner production and products, and sustainable development of regions.

Austrian Environmental Technologies Database. The Federal Ministry for Economic Affairs established an electronic database in 1997 enabling Austrian firms doing business in the area of environmental protection to text search for products and keyword search for processes and industrial services. The reference service covers the categories of: water and wastewater treatment, waste management and recycling, cleanup and soil rehabilitation, air and noise pollution control, energy efficiency and new and renewable energy technologies. It links enterprises, manufacturers of environmental technologies, engineering consultants and related information services. A comprehensive index system allows a firm to locate suppliers with solutions that match their specific requirements. The electronic database has proven successful in promoting the use of new environmental technologies and in diffusing these techniques to smaller firms.

Canada

Canadian Business Environmental Performance Office (BEPO). BEPO provides electronic access to environmental and business information along three functional lines: waste management (liquid, solid, and air waste management strategies as well as hazardous waste handling practices), health and safety management (emergency planning, environmental risk management, hazardous substance management, and health and safety issues), and resource conservation and pollution prevention (water and energy conservation, green procurement, environmental management systems, pollution prevention planning, waste minimisation and pollution prevention tools).

Canadian Environmental Technology Advancement Centres (CETACS). In partnership with provincial governments, environmental industry associations, and the private sector, the federal government supported the establishment of three Canadian Environmental Technology Advancement Centres, or CETACS. Private sector, not-for-profit organisations that operate at arm’s length from government, their goal is to help SMEs commercialise environmental technologies by providing a wide range of services: assistance in accessing investment capital, general business development counselling, technical and legal services, market analysis, and strategic advisory services. By making information on these technologies widely available, the CETACs contribute to their diffusion.

One of the CETACs, the *Ontario Centre for Environmental Technology Advancement (OCETA)*, is playing a key role in the establishment of Services and Information on Ecotechnologies (SIE), which provides an electronic information service intended to assist waste generators in making environmentally and economically sound choices. Supported by the Commission for Environmental Cooperation, established under the North American Free Trade Agreement, the newly incorporated SIE launched a demonstration Web site that indexes surface cleaning issues to technologies available in the three NAFTA countries.

Environmental Technology Verification (***ETV*)*.*** This programme is designed to provide validation and independent verification of performance claims for environmental technologies and equipment-based services. To be eligible for the ETV programme, the technology must be an environmental technology or service whose performance can be verified; offer an environmental benefit or address an environmental problem; meet minimum Canadian standards and/or national guidelines for the technology type; and be currently commercially available or commercially ready for full-scale operation. For the claim to be verified, ETV must certify that the technology provides a benefit or addresses an environmental problem and is based on sound scientific and engineering principles, that it is fully supported by peer-review data generated through an independent testing process, and that the conditions of performance are clearly defined. Verification certificates are awarded to successful applicants, and these can be of considerable value in facilitating the diffusion of the technology.

Denmark

Cleaner Technology Action Plan. Through its Cleaner Technology Action Plan, the Danish government offers a suite of services to promote the diffusion of environmental technologies. The Plan was devised by the Danish Environmental Protection Agency (EPA) and many of its projects have been sponsored by the National Council for Recycling and Cleaner Technology. The initial Action Plan, currently in its third phase, began in 1986. The third phase, which will run through 1997, builds on initiatives launched in the first two phases. The goals of the Plan are to prevent environmental damage by promoting cleaner technology and to limit the consumption of resources. End-of-pipe technologies are not considered in the Plan, although they are acknowledged to have a continuing important role in Danish industry. Activities are directed principally toward industry decision makers and managers, but an aim of the Plan is also to educate and influence politicians, public purchasers, ordinary customers and technical and environmental staff in Danish municipalities.

The Action Plan combines both R&D activities and diffusion activities, and these are supported by grants or subsidies. Over the five-year third phase of the plan DKK 380 million have been allocated for the study, development, demonstration and promotion of the use of cleaner technology in Danish companies. Environmental technology diffusion is specifically promoted through information dissemination, technical support (e.g. through the use of consultancy services to conduct environmental audits), demonstration programmes and voluntary agreements with industry. The sectors targeted by the Action Plan are numerous and include the iron and metal, fishing, wood and furniture, chemical, textile, biotechnology, agriculture, and photography and printing industries, plus, among others, slaughterhouses, dairies, dry cleaners and laundries.

One project that illustrates the information dissemination component of the Action Plan was directed toward the iron and metal industry. To help educate the designers of industrial products, a guidebook was produced that discussed general guidelines for environmentally-friendly uses of steel as a construction material. The guidebook emphasised the evaluation of the use of steel from a life-cycle perspective and included specific recommendations for taking environmental considerations into account in designing and producing steel products. A second example is that of the development of a construction contractor’s environmental guide. The guide is intended to be used for introducing environmental management principles to contractor companies and is composed of an information package designed for each stage of the construction process and for the needs of different types of personnel. Finally, as a third example, the Action Plan recognises that financial institutions may have an important role to play in promoting environmental technology diffusion. The Plan notes that financing institutions have funds to invest in cleaner technologies and that companies very much need such investments. However, these investments are not made to the extent necessary because of a lack of communication between financing institutions and companies. The Action Plan aims to promote greater communication between these entities.

An interesting example of a voluntary trade agreement was implemented in 1991 among industrial users of polyvinylchlorides (PVCs). Firms using PVCs agreed to try to reduce and/or find new substitutes for them. Many companies mention this agreement as the stimulus that led to the development of alternative, more environmentally-friendly products, and, indeed, total consumption of unprocessed PVCs dropped from 65 000 tons in 1988 to 51 000 tons in 1994. However, significant quantities of PVCs are still being used, and it appears the agreement was insufficient relative to the overall need to find substitutes for PVCs and that, in general, such agreements “cannot stand alone but must be supported by other instruments”. An example of a demonstration project is that of the “recycled house”. The goal of the project was to erect a new building as part of an urban renovation project in Copenhagen using as much recycled construction material as possible. The project demonstrated how to reduce waste, which in turn led to a reduced need for landfilling, raw materials, energy and materials transport. As part of the project, a handbook was produced which described control procedures that must be employed when selecting recyclable materials.

SME Programme. A more general programme within the Action Plan was established in 1994 specifically to help small and medium-sized enterprises (SMEs). The multiple objectives of this programme were to increase the number of SMEs with environmental policies and action plans; to improve the environmental, health and safety performance of SMEs; to increase investments in cleaner technology and energy saving equipment; to improve the environmental awareness of existing staff members; to strengthen co-operation and networking among enterprises, local authorities, training programmes and consultants; and to increase the sales of environmental products, systems and services. Individual projects cover a wide variety of activities, from product and process development, to improvements in resource management systems. To qualify for support, projects *must*, among other things, execute one or more improvements; establish an environmental policy, targets and action plan; involve staff in planning and implementation; and hire new staff with environmental expertise. To accomplish these objectives, the Danish government budgeted DKK 80 million through 1997. The programme funds up to 50% of the costs of a project of an SME or group of SMEs up to a limit of DKK 400 000. Covered costs may include costs for new employees engaged in environmental work, internal wages for project activities, expenses for development and testing of new environmental technologies or processes, staff training, and, in part, costs of external consultants.

Thus far, more than 200 different SME projects have been implemented. Hiring of additional skilled staff was considered to be one of the most important factors in successful projects, and more than 80% of new staff stayed in their jobs after the completion of the project. Many enterprises stressed the importance of the compulsory elements of the programme, the systematic approach required and the involvement and training of existing employees. Surveys show that all companies involved in the programme have plans for further improvements. Another successful outcome appears to be significantly improved co-operation and understanding among the three administering agencies (i.e. the Danish EPA, the National Technology Agency, and the Danish Working Environmental Service), the local authorities, and the companies, as well as an improved network linking companies and environmental consultants.

France

***Agence de l'Environnement et de la Maîtrise de l'Énergie** (ADEME)*. ADEME is an important French organisation for promoting environmental technologies and energy conservation. It was created as a public institution in 1992 by the consolidation of the French Agency for Energy Management, the National Agency for Recovery and Elimination of Waste, and the Air Quality Agency. It's multifaceted mission is to assist industry and commercial enterprises to reduce usage of energy and raw materials, to promote the use of renewable energy, to encourage the use of clean and efficient technologies, to limit waste production and maximise recovery and reuse of waste, to reduce noise pollution and to prevent and/or treat soil pollution. ADEME's annual operating budget of over FRF 1.3 billion is derived from supporting ministries and from the special taxes it collects from activities that cause atmospheric pollution, airport noise, industrial waste, etc. Its three principal centres in Paris, Angers and Valbonne Sophia Antipolis, and its 26 regional offices employ approximately 600 people. Like its Dutch counterpart, ADEME promotes technology diffusion through an integrated, multi-tiered programme that combines national and regional elements.

ADEME carries out its mandate through support for applied research and through an array of programmes promoting technology diffusion. Although the institution does not carry out research *per se*, it provides assistance to those who do. It participates in many joint programmes with private research laboratories, technical centres and the *Centre National de la Recherche Scientifique* (CNRS). For example, ADEME and CNRS co-financed eleven environmental engineering projects through CNRS's Ecotech programme.

More broadly, ADEME promotes research and technology diffusion in a variety of industrial and other sectors. These include iron and steel, chemicals, textiles, paper, construction materials, electronics, buildings, agriculture, transport and renewable energy.

As noted, much of ADEME's budget is derived from environmental taxes that it manages. For example, one such tax is levied on atmospheric pollution. The tax is applied to emissions of sulphur dioxide, volatile organic compounds (VOCs), nitrous oxides and hydrochloric acid and contributes to the development of new pollution prevention processes. Hence, at least 60% of the amount raised is used by ADEME to finance new equipment for eco-industries; the remainder is used to support technology development.

ADEME's information programme is a major effort to promote the diffusion of environmental technologies. Each year a different theme is stressed. In 1996, for example, the accent was on waste problems and atmospheric pollution. ADEME publishes a broad range of practical guides written for the needs of enterprises. Generally, ADEME's guides are inexpensive but not free. A recent catalogue lists some 90 different guides. One example is a guide to reducing industrial emissions of volatile organic compounds. As is typical, this guide provides an inventory of technologies for reducing VOCs and concrete examples of how to apply the technologies. Another example is a recent publication which describes the implementation of 50 clean technology projects. Guides are intended both to inform and to help in decision-making.

In addition to producing guides and other printed material, ADEME promotes diffusion through its hosting of symposia and technical meetings. For example, the combined ADEME "Energy 97" and "Pollutec 97" conferences were held recently. Over 1 300 exhibitors participated and approximately 40 000 people attended, giving ADEME the opportunity to engage both the public and private sectors in thinking about energy efficiency, the development of renewable energy, and the prevention of pollution and pollution impacts. ADEME described the conference as the "world crossroads for new environmental technologies". ADEME also conducts training in association with various partners, for example, on waste management. Broader public awareness is promoted through open houses, dissemination of information through Minitel, and the sale of documents and videos. ADEME established a Web site, which was expected to be fully operational in 1998. Finally, *La Lettre ADEME* is a monthly letter reporting the latest news on energy and environmental technology developments and targeted to enterprises and regional governments.

Environmental management is promoted through ADEME's *Enterprise Environment Plan* (PEE). This plan has been jointly developed with the Ministry of Industry and the Ministry of the Environment to help enterprises improve their energy and environmental management and to enable them to qualify for ISO 14001 certification or to pass an eco-audit. The PEE is intended especially for SMEs. Implementation of the plan allows firms to reduce energy consumption and waste production and to limit discharges of pollutants at an economically acceptable cost. Two documents have been produced, one intended for company heads that discusses how to initiate and track environmental management, the second for key environmental personnel which gives recommendations and suggests practical steps to take to implement the plan.

ADEME (in conjunction with the magazine *Industry and Technology*) also promotes technology diffusion through an annual "Clean and Efficient Technology" prize. The prize is given to recognise industrial enterprises that have rethought fabrication processes and have been able economically to substitute polluting compounds, develop clean processes, recycle, or put waste with high energy potential to use. Since 1993, 20 enterprises, both large and small, have been awarded prizes. One-third of the achievements honoured have dealt with different approaches for reducing VOCs.

Germany

Bavarian Environmental and Consulting Programme. An important programme in Germany is the regional Bavarian Environmental and Consulting Programme. This programme was begun in December 1996, replacing an earlier programme that had subsidised approximately 3 200 SMEs in an effort to increase their environmental performance. Like its predecessor, the key elements of the new programme include *subsidies* and *technical assistance*. All sectors are eligible.

The objectives of the programme are: *1)* to provide Bavarian SMEs with an evaluation of their environmental performance, focusing especially on air, water, and soil; *2)* to help SMEs develop effective strategies to address environmental concerns, including, for example, strategies to help them comply with environmental legislation; and *3)* to identify environmental cost savings or revenue-increasing possibilities and to suggest ways of financing proposed measures. In keeping with these objectives, the programme also helps SMEs obtain certification under either the European Union’s voluntary Eco-Management and Auditing Scheme (EMAS) or the International Organization for Standardization’s environmental management system (EMS) standard ISO 14001. ISO 14001 is a worldwide standard on EMS certification. The EMAS is a voluntary regulation set up by the European Union in 1993. Its goal is to encourage companies to introduce environmental management into their general management system and to control and continuously improve their environmental performance. EMAS is voluntary, but certified companies are registered on a documented list of companies that manage their environmental performance to high standards – a major encouragement to progressive enterprises.

The programme operates by providing consultants at subsidised rates to undertake the analyses or audits. The basic subsidy for SMEs (defined as enterprises having a turnover of under DEM 30 million) is 80% of total costs up to a maximum of DEM 30 000. Subsidies that vary depending on the turnover and/or size of the SME are also available to implement ISO 14001. The subsidies are granted by the *Landesgewerbeanstalt Bayern*. Promotion of the programme is through Chamber of Commerce publications, posters and newspaper articles.

At the federal level, the ***Federal Foundation for the Environment (DBU)*** is funding development and diffusion of environmental technology. The main aim of the foundation is to support SMEs in their activities in the environment field. Since its establishment in 1991, more than 2 600 projects have been funded with 1.3 billion DEM.

Hungary

National Environmental Programme (NEP). Hungary has several programmes intended to develop and disseminate clean and energy-efficient technologies to industry as part of its National Environmental Program (NEP), which aims to increase the share of environmental protection expenditures to 1.7% of the gross domestic product (GDP) by the year 2002. A Central Environmental Fund, comprised of government funding, environmental fines and environmental product liability charges, has been established under the Ministry of Environmental Protection; at least 75% of the resources are allocated to grants or loan guarantees for investments in environmental technology development and dissemination. This is supplemented by funds received under the European Union PHARE programme in the amount of ECU 100 million per year for the diffusion of environmental technologies in eastern European countries.

In addition, the National Committee for Technological Development (OMFB) is supporting the development and diffusion of environmental technologies through its general fund for applied research and development. In the most recent awards, approximately 15% of funding was devoted to environmental projects, which could receive up to HUF 40 million for a three-year period. The OMFB, the Ministry of

Economy and the Ministry of Environmental Protection are now developing a National Environmental Technological R&D Programme, which is to develop and diffuse environmental technologies in fulfilment of the objectives of the National Environmental Programme with yearly structured objectives.

Ireland

Clean Technology Centre. The Clean Technology Centre (CTC) in Ireland is an independent, non-profit corporation supported by a combination of public and private sources. Specifically, 14 sponsoring companies contribute to the CTC's funding through an annual subscription fee, while additional funds are provided by the European Regional Infrastructure Development Programme (via Forbairt, the Irish State Agency for Science and Technology). Also of note is that the Centre is based at the Cork Regional Technical College and has strong links with this technical educational institute.

The mission of the CTC is to advise and assist industry, public authorities and governments on the adoption of waste minimisation techniques, clean technologies and cleaner production methods. The Centre aims to help industry shift away from a focus on end-of-pipe technologies to control pollution to one based on pollution prevention. The programme provides expertise and services to "once-off" clients requiring solutions to specific problems as well as ongoing environmental services to its sponsoring companies. Although the original sponsors were mostly pharmaceutical and chemical businesses in the Cork City region, the Centre currently provides industrial services to companies from a wide variety of industrial sectors throughout Ireland. It has also carried out projects for the European Commission, Forbairt, the Irish Business and Employers Confederation and the Irish Environmental Protection Agency (EPA).

One pertinent European Commission project in which the CTC is currently involved concerns development of societal mechanisms and management practices for the establishment, implementation and maintenance of local sustainable production programmes (SPPs). The CTC is working in collaboration with partners from the Netherlands, Italy, Portugal, Austria and Denmark to study past cleaner production projects and undertake detailed socio-economic analyses of specific local areas. The aim is to understand the factors that influence the probability of success of SPPs, set up general SPP guidelines for local communities and other actors, and formulate novel strategies to stimulate industry (and SMEs in particular) to adopt sustainable production practices.

The CTC provides mainly *technical services* and *information* in six important areas. Thus, CTC carries out *waste minimisation assessments* which may include waste audits, suggestions for process and operational modifications and identification of cleaner technologies. It provides *process engineering consultancy services*, which may include feasibility and desktop studies, eco-design of products, technology transfer assistance, etc. It assists companies in designing and implementing *environmental management systems*. This service begins with an initial appraisal of current management structures and procedures and an assessment of the scope of work necessary to gain accreditation to the relevant environmental management standard. CTC provides *training* and *disseminates information* to companies on such topics as waste minimisation, environmental management and safety. It assists companies in obtaining and maintaining *integrated pollution control* licenses, and through its Information Office, is able to provide information on the details and significance of current national, European Union and international *legislation* related to cleaner technologies and waste minimisation. Additional services include environmental impact report preparation assistance, environmental audits, advice on facility installation, and identification and implementation of product recovery technology.

The companies that helped sponsor the CTC are committed to sustainable production techniques and, through the CTC-suggested changes they have made, provide a valuable example to other companies of the possibilities of using clean technology and cleaner production. Their success in meeting and surpassing Integrated Pollution Control regulations imposed by the Irish EPA is one example. Also, several have been awarded national and/or international awards for their improved environmental performance. Finally, environmental lobby groups and local authorities have acknowledged that the improved environmental performance of the companies has led to improved environmental quality in areas where they are located.

Environmental Audit Grant Scheme. Another programme in Ireland is more narrowly focused on providing environmental audits. The Environmental Audit Grant Scheme (EAGS) is operated by Forbairt in part with funds provided by the European Regional Development Fund. The objective of the programme is to stimulate and support SMEs to improve their environmental performance without hurting their profits. Qualifying SMEs are granted up to 50% of the costs (up to a maximum of IEP 5 000) of conducting an audit. The audit procedure consists of four steps: *1)* a pre-audit visit so that auditors can become familiar with the facility and obtain existing information and licenses; *2)* a planning session in which the full audit team is selected and information requirements are identified; *3)* the actual audit, during which the site and equipment are inspected and records are examined; and *4)* report preparation, beginning with a draft report and discussions with the client and concluding with a final report containing recommendations. Among other things, the new programme has helped businesses identify cost savings through implementation of waste minimisation practices, plan investment programmes to meet higher environmental standards in the most cost effective manner, and prepare for Integrated Pollution Control Licensing and the setting up of Environmental Management Systems.

The Netherlands

Cleaner Production Programme. An important example in the Netherlands of a programme to promote diffusion of environmental technologies is the Cleaner Production Programme (CPP) initiated and funded jointly by the Ministry of Economic Affairs and the Ministry of Housing, Spatial Planning and the Environment. This programme was launched in 1992 and had funding of NLG 3.6 million for an initial period of just over three years. However, the initiating ministries were so pleased with the results that they decided to extend the Programme at least through 1998. The main objective of the Cleaner Production Programme is to stimulate the utilisation of clean technology in the small and medium-size business sector.

The Cleaner Production Programme is executed by an integrated network of Dutch organisations, including the Netherlands Innovation Centres Network, the National Environmental Centre (NEC), 18 regional Innovation Centres (ICs) and some 20 Regional Industrial Environmental Agencies (RIEAs). The integrated nature of the Programme is one of its most interesting elements and one that other countries may find useful to emulate. The CPP is designed to reach essentially all businesses in the Netherlands, but it has identified 11 industries for special attention: the foodstuffs and stimulants industry; the wood and furniture industry; printing and allied trades; the chemical industry; the rubber and plastics processing industry; the building materials, earthenware and glass industry; the metal products industry; the engineering industry; the motor vehicle industry; the building industry; and repair shops for consumer goods. In all, there are approximately 105 000 SMEs in the Netherlands in these target groups.

The programme is focused on disseminating information about cleaner production, and is organised principally around a four-tiered communication model: *1)* the national communication tier emphasises information dissemination through the mass media, trade journals and data banks; *2)* the regional information tier focuses on informative meetings and training courses; *3)* activities related to trade and industrial organisations include training courses, manuals and fact sheets, and discussion platforms; and *4)* the "individual advice" tier provides consultancy services to individual companies.

The Innovation Centres Network and the National Environmental Centre took the lead in promoting national-level activities that focused on raising awareness about cleaner production among SME entrepreneurs. One major activity is the production of several magazines and newsletters, including *InnoVisie* and *Nieuwsbrief Milieutechnologie*, that discuss cleaner production practices, give examples of successful projects, etc. A second national element is production of a televised educational course on cleaner production for entrepreneurs. All those who could potentially benefit from the course are mailed brochures. The final component deals with disseminating information about the so-called VA-Mil scheme, a subsidy that allows entrepreneurs the opportunity to depreciate investments they have made in certain environmental measures or facilities faster than would normally be the case.

The lead agencies for the regional programme are the Innovation Centres (ICs). These Centres focus on organising regional meetings (and accompanying brochures) on environmental technology, innovation and energy topics. Meetings are tailored to meet the needs of specific industrial sectors in specific regions. In conjunction with the RIEAs, the ICs also organise courses on prevention of waste and emissions. The courses give participants a step-by-step method (the PRISMA method) to explore the options available to improve environmental performance, including, for example, the possible introduction of new technologies, changes in the production process or substitution of raw materials.

Projects in the tier concerning activities with trade and industrial organisations also focus on providing information, but through collaboration between trade and industrial organisations and the National Environmental Centre (NEC). The IMPRES project (in Dutch, an acronym for innovation, environmental management, prevention of waste and emissions, and collaboration), for example, is a partnership between the NEC and the South Holland Pollution Prevention Team to promote the introduction of environmental technology and innovation in certain industrial sectors. Sector-specific activities included production of manuals, organisation of training courses and provision of individualised advice. Consultants were provided by the RIEAs and ICs, and activities are designed to reach as many enterprises as possible in each sector targeted. More broadly, the NEC supports the development of various kinds of information materials for use by environmental managers, municipal and provincial authorities, entrepreneurs, and the RIEAs and ICs. Publications for entrepreneurs give practical examples and explain, step-by-step how to prevent waste and emissions. Some of these products are disseminated by trade and industrial organisations; others are produced for sale.

The individual advice tier of the CPP is based on a finding that many SMEs cannot easily afford the services of an environmental consultant. Hence, the RIEAs and ICs provide, either free of charge or for a small fee, simple environmental audits known as “environmental scans”. RIEAs focus on regulatory and licensing issues while the ICs provide advice on technology issues. The result of each scan was a report that outlined the environmental risks a company faced and options for improvement. Follow-up advice was also provided when requested.

The decision to renew the CCP for at least three additional years is an indication of the Programme’s first-phase success. Sponsors of the Programme were pleased with the effectiveness of the four-tiered communication model used. Each of the components of the CCP had quantitative objectives expressed in terms of such statistics as the number of meetings held, number of courses taught or number of environmental scans made and, in all cases, these objectives were exceeded. The environmental scans conducted for individual companies appear to have been very well received. But perhaps the most important lesson learned from the Programme, according to the evaluation done at the end of the first phase, concerned the value of integrating national, regional and individual elements into one unified programme. This proved not only an effective way to communicate to SMEs but also motivated significant co-operation and cross-fertilisation among the ICs, RIEAs, and other collaborating organisations.

Norway

GRIP Centre for Sustainable Production and Consumption. Norway's GRIP (Green Management in Practice) Centre for Sustainable Production and Consumption is involved in environmental technology diffusion primarily through its programmes to stimulate adoption of innovative management practices in Norwegian businesses and the public sector. Information dissemination and demonstration are the key approaches employed. The Programme is based on the concept that sustainable development and, to use GRIP's term, eco-effectiveness make good business sense. In particular, GRIP notes that customers are increasingly demanding environmentally-friendly products, and, therefore businesses that can satisfy these demands can gain a competitive advantage. Companies that wish to benefit from GRIP's expertise are provided with a package of materials on eco-effective organisational development.

GRIP's programme is targeted toward SMEs and, given that GRIP believes businesses should not become dependent on external environmental consultants, is based on a do-it-yourself philosophy. One aspect of this philosophy is that GRIP advises organisations to establish an environmental leader who reports directly to top management. GRIP also encourages a holistic approach wherein environmental management is addressed at all management levels. The Programme has thus far focused on commercial buildings, retailing, public sector procurement, information technology and communications, advertising, banking and finance and automobile renting and sharing.

In the commercial buildings sector, GRIP has conducted a pilot project to demonstrate that selective demolition with material sorting can more than halve waste volume without increasing costs above those normally incurred. In collaboration with partners, GRIP also published a manual that described a methodology for taking environmental criteria into account in designing and building structures. GRIP has also conducted a pilot project in the retailing sector. Elements of the project involved preventing waste by including environmental criteria in procurement policies, influencing customer purchasing decisions by adding environmental information to labels, and recycling packaging wastes.

An important public sector programme was undertaken to motivate local authorities to include environmental criteria in purchasing decisions. This programme apparently had an upstream effect in that it stimulated suppliers to give consideration to environmental criteria as well. As a follow-up to the pilot programme, a manual for purchasing officers has been written. With respect to information technology, GRIP has focused on increasing general market awareness of opportunities for using emerging technologies to make businesses more efficient. Finally, in the banking and finance sector, GRIP is helping to stimulate the consideration of environmental criteria in lending policy and portfolio management. For example, it is funding a prize for the company that provides the best environmental information to the investment community and is supporting the development of competence on portfolio management tools.

Sweden

Swedish Delegation for Sustainable Technology. Established in 1996, as an independent authority under the Ministry of Industry and Commerce, the task of this Delegation is to stimulate commercialisation, faster market introduction and increased sale of products that reduce environmental impact and offer opportunities for industrial development and job creation. Instruments used include mediating the procurement of products which are based on more sustainable technology, information dissemination, and organisation of competitions and seminars in four priority areas: transport, construction and housing, food and agriculture, and ecological remediation of soil.

United Kingdom

Environmental Technology Best Practice Programme. The ETBPP, which focuses on waste minimisation and the use of cleaner technologies, is jointly funded by the UK Department of Trade and Industry and the UK Department of the Environment, Transport and the Regions and is managed by AEA Technology plc through the National Environmental Technology Centre and the Energy Technology Support Unit. Thus far, the Programme has targeted 11 different industrial sectors: the foundry industry, textiles, paper and board, volatile organic compounds, glass, food and drink, chemicals, printing, metals finishing, ceramics engineering, and plastics and packaging. Four distinctive programme elements, three focused on providing information and one on financial assistance, comprise the bulk of the ETBPPs work: *1)* the production of "good practice" guides and case studies, *2)* the production of environmental performance guides, *3)* the presentation of "new practice" case studies, and *4)* the promotion of "future practices". Information is generally provided free of charge.

The good practice guides and case studies provide examples of proven, cost effective measures that have improved environmental performance. They often contain information on how good practices can be profitable. An example of a good practice case study is one that examined the methods and technology used at a foundry, Triplex Alloys Ltd. The aim was to demonstrate the economic, environmental and technical benefits of thermally reclaiming chemically bonded foundry sand. Good practice guides have been published not only to disseminate information on proven technology but also to inform firms about good management practices. For example, "Environmental Management Systems in Foundries" is a workbook that provides a step-by-step approach to environmental management in the foundry industry. It is designed to allow a foundryman with no previous experience of environmental management to carry out an environmental effects review, write an environmental policy, set goals, and then implement environmental management system.

The environmental performance guides provide information through reporting the results of benchmarking studies that compare industry-wide practices. One example is a guide detailing the main findings of a survey of 105 UK foundries that use chemically bonded sand. Various statistics are presented that allow individual foundries to compare how well they are doing (e.g. in amount of sand used to castings produced) relative to the average for the industry and to those with the best performance. The guide also contains a Sand Action Plan, which includes suggestions to help companies reduce sand costs and use and to optimise the disposal and/or reclamation of used sand.

The new practice case studies monitor and promote new environmental technologies and evaluate their benefits to increase awareness, acceptance and adoption. One new practice project applicable to waste treatment in the dairy and food industries concerns the use of biological digestion to reduce the strength of abattoir effluent and produce compost as a by-product. This case study gives details of anticipated costs and environmental benefits and has attracted over 300 inquiries from potential investors.

The focus of the Future Practice element of the ETBPP is financial support of research and development (R&D) of new environmental technologies. For example, the Programme has contributed to the R&D costs of a group of companies engaged in building a prototype timber treatment plant. The plant will be used to assess and develop the most effective way of applying pesticides and weatherproofing to timber without the use of solvents. A future practice "profile" of this work has been published.

In addition to these four central programme elements, the ETBPP also operates an environmental helpline, conducts free site visits, organises events such as seminars and workshops, and is active in monitoring and facilitating waste minimisation clubs. The environmental helpline provides up to two hours of confidential advice to UK businesses on queries related to environmental technology, legislation and other issues.

Half-day site visits are offered to companies employing less than 250 people. During such visits an environmental counsellor provides advice on best environmental practices; after the visit, the counsellor produces a follow-up report containing suggestions for improvements. Both general and industry-specific workshops have been organised for presentation to companies and industry groups. One general workshop that many companies have found useful, for example, is based on the Good Practice Guide *Cutting Costs by Reducing Waste: A Self-Help Guide for Growing Businesses*.

The Programme has been replicated in about 45 waste minimisation clubs with ten more in the pipeline. These clubs have been formed to help local businesses and small companies minimise waste and improve environmental performance through the exchange of information on technologies, methods and management practices used. For example, the Scottish Enterprise Tayside Food Sector Waste Management Club was organised by five companies. Each contributed GBP 3 000 and matching funds were provided by Scottish Enterprise Tayside. The problems of the five companies were similar in nature, so options for change identified by experts were relevant to all. The participating companies identified total savings of GBP 290 000 during the year-long pilot project and estimated future annual savings at more than GBP 1 million. The results of such projects as this may be disseminated to other businesses as well.

The ETBPP published its 2nd Annual Review in October 1997 covering the years 1996/97. The summary notes that the environmental helpline received over 500 calls a week and that 300 small companies took advantage of the free counselling service. Although the rate of industry implementation of new practices has not been quantified, the ETBPP reports that there has been a clear and sustained increase in the level of environmental awareness by UK businesses.

Energy Efficiency Best Practice Programme. The goals of EEBPP are similar to those of the ETBPP, although the focus is on improving energy efficiency. The Programme addresses four barriers to greater energy efficiency: the limited understanding of the potential benefits of energy efficient technologies and techniques; the lack of objective information on both existing and novel energy efficient technologies; institutional barriers, particularly within the buildings sector; and the weak and fragmented nature of parts of the UK energy efficiency industry. The EEBPP has four integrated programme elements, which mirror the major elements of the ETBPP. Thus, the Programme produces energy consumption guides, good practice guides and case studies and studies of new practices; it also provides some financial support for future practices.

The energy consumption guides are essentially benchmarking guides that provide data on how energy is currently used within particular industrial sectors or for different processes or building types, allowing organisations to compare their own energy usage with that of others in equivalent organisations. Each guide contains an Action Plan of achievable energy saving measures to encourage firms to take the appropriate first steps toward becoming more efficient. Guides may be promoted through workshops and seminars, targeted mailings or articles in the technical press.

As with the similar ETBPP good practice guides, the energy efficiency guides give information about best practices currently associated with energy use in a particular industry. The types of material provided may include information on specific energy efficient technologies, design considerations, management techniques, operating practices, education and training, and staff motivation. Case studies complement the guides and offer concise, specific examples of proven energy efficiency measures. To be used as a case study, a project must have been determined to have the potential for stimulating national energy cost savings of more than GBP 0.5 million per year.

The new practice component of the programme strives to provide information that will stimulate confidence in new energy efficiency measures just becoming available. An example is the reporting of a new technique that uses anaerobic digestion as part of a paper mill effluent treatment system. The host paper mill for this project saved 60 000 primary gigajoules of energy worth abut GBP 150 000 per year compared to a conventional aerobic installation. At least one other paper mill has installed this system and others are anticipated to do so.

The future practice component of the EEBPP provides financial support for basic R&D into new energy efficiency measures. The programme provides up to 49% funding for appropriate multi-client future practice projects, with special funding available to small and medium-sized enterprises. The EEBPP cites the development of small-scale combined heat and power (CHP) systems as one Future Practice success story: the supported R&D has resulted in the continued and rapid uptake of this technology, and installed capacity in 1993/94 amounted to over a quarter of the estimated market potential for this CHP application. Project findings are published in Future Practice Reports and Profiles.

The EEBPP programme was established in 1989 and thus has had more time to study and quantify results than the related ETBPP. These have either been expressed by energy savings made by individual companies or, where possible, by savings in sectors or whole industries. One example notes the results obtained by two aerodynamic truck projects: over a two-year period, and largely as a result of project and promotional events, the number of aerodynamically-styled trucks in operation increased significantly. Fuel savings per new truck were estimated to be 5 500 litres per year.

United States

There are probably more than 200 separate Federal and State programmes that address one or more aspects of environmental technology diffusion in the United States. Here, five programmes with different types of features are discussed.

Design for the Environment. The Design for the Environment (DfE) programme is one (of many) voluntary EPA programmes related to environmental technology diffusion. Established in October 1992, the programme is designed to help businesses incorporate environmental considerations, such as risk reduction, into the design and redesign of products, processes and technical and management systems. Design changes may have to do with implementing pollution prevention, energy efficiency and other resource conservation measures; making products that can be refurbished, disassembled and recycled; or keeping careful track of the environmental costs associated with each product or process.

The programme is focused on compiling and disseminating information needed to design for the environment and on developing new analytical tools for use by business. A typical DfE industry project includes developing a Cleaner Technologies Substitutes Assessment (CTSA) and a communication and implementation strategy. By providing detailed environmental, economic and performance information on traditional and alternative manufacturing methods and technologies CTSAs help companies compare different technologies or products and select the most environmentally-friendly alternatives. To help industry implement some of the new technologies identified in the CTSA, DfE provides a variety of outreach tools, including fact sheets, bulletins, pollution prevention case studies, software, videos and training materials. Some of the CTSAs that have been undertaken include those for printed wiring board, screen printing, lithography, flexography, garment and textile care, and metal finishing.

Several standardised products are also being developed. One is a generic assessment procedure that will help companies conduct their own in-house assessments. A second is a method to help companies evaluate the environmental effects of a product, process or activity throughout its life-cycle (from raw material extraction and production through final disposal). A third, which is being done with the assistance of the private sector, is to develop new and modified accounting tools to help enterprises incorporate environmental costs and benefits into managerial accounting and capital budgeting practices.

One other interesting element of the DfE Programme is an attempt to interact with the financial community to find ways to address the difficulty of financing new pollution prevention technologies. EPA notes that the difficulty of financing such technologies is an important constraint on their uptake, in part because the financial community tends to associate environmental investment more with liability than opportunity, in part because financial institutions and businesses have not known how to estimate the returns on pollution prevention investments.

Green Lights Programme. EPA's Green Lights Programme, launched in 1991, is a particularly effective voluntary programme. The focus is on promoting energy efficiency in the lighting sector through a public-private partnership that combines technical support and information provision. The goal of the programme is to prevent pollution by encouraging major US institutions (i.e. businesses, governments, and other organisations) to use energy-efficient lighting. Because lighting consumes about 25% of total electricity used nationwide and because more than half the electricity used for lighting is wasted, the Green Lights Programme offers a substantial opportunity to prevent pollution – and to do so at a profit. Lighting upgrades reduce electric bills and maintenance costs and increase lighting quality. EPA notes that typical investments in energy-efficient lighting yield rates of return of 20 to 30% per year.

EPA promotes energy-efficient lighting by asking major institutions to sign a memorandum of understanding with the Agency. The signatory commits to install energy-efficient lighting in 90% of its space nationwide over a five-year period, but only where it is profitable and where lighting quality is maintained or improved. EPA, in turn, offers programme participants a number of technical support services to assist them in upgrading their buildings. A computerised decision support system developed by EPA provides Green Lights corporations and governments a rapid way to survey the lighting systems in their facilities, assess retrofit options and select the best energy-efficient lighting upgrades. EPA has also established a national lighting product information programme in conjunction with utilities and other organisations. This programme provides brand name information so that purchasers will be able to choose products with confidence. In addition, it allows for innovative products to be qualified rapidly, removing an important barrier for new technologies. Institutions that join the programme can benefit by advertising how they are helping to improve the environment.

As part of the support programme, EPA helps partners identify financing resources for energy-efficient lighting. Green Lights Partners receive a computerised directory of financing and incentive programmes offered by electric utilities, lighting management companies, banks and financing companies. The database is updated and distributed on a regular basis. EPA also has developed Green Lights Ally programmes for lighting manufacturers, service providers and utilities to promote the environmental, economic and quality benefits of energy-efficient lighting. Allies commit to the same level of retrofits as Green Lights Partners and assist in developing the technical support programmes. Over 2 000 organisations have participated in the Green Lights Programme to date and have committed themselves to upgrade more than 4 billion square feet of facility space – more than three times the total office space of New York, Los Angeles and Chicago combined. EPA also notes that savings in electricity now amount to over USD 12 billion per year and that air pollution has been cut by approximately 5%.

Innovative Concepts Programme. This Department of Energy (DOE) programme provides seed-money grants to encourage energy innovation and help new technologies move more quickly from the conceptual state into the marketplace. The programme seeks to be the "first funder" for concept-stage technology in specific problem areas, such as waste minimisation and utilisation. The seed funding is intended to fund concept definition to a stage at which other prospective sponsors can more clearly assess the potential of the concept. After grant completion, the funded projects showcase their technologies at a technology fair, which is the primary mechanism for exposing potential sponsors to the concepts.

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TECHNOLOGY FORESIGHT FOR THE ENVIRONMENT

SUMMARY

Advanced sensors, biotechnology and clean cars top the list of important environmental technologies for the future identified by the technology foresight exercises of the major OECD countries. Also on the consensus list are new product recycling technologies, smart water and waste treatment, micro-manufacturing, and advances in renewable energy and photovoltaics. Environmental issues are becoming predominant in foresight surveys which highly rank technologies for achieving sustainable development goals. According to these surveys, technical advances to address both local and global environmental problems are among the most important issues for the future.

Technology foresight helps countries identify significant areas for research and development. It aids in setting priorities for government research in an era of tight budgets. It indicates areas for investigation by industry. Foresight exercises target technologies which are needed for achieving social goals in areas such as health and environment as well as economic objectives such as industrial competitiveness. As markets for environmental goods and services grow, picking the right environmental technologies is both good for the environment and good for business. And the process of technology foresight – carried out through Delphi surveys, large-scale consultations or developing lists of critical technologies – is itself valuable in forging linkages between society and research. Environment-related technology foresight is creating networks of people sharing a common view of how to realise sustainable development.

Environmental technology is not a distinct field like advanced materials. Whether using biotechnology or information technology, it is defined by the objective of protecting the environment. Foresight results show that environmental technology is diffuse and often interdisciplinary. It is also an area that requires long time horizons to develop. Sustained government research support is crucial in areas where industry may under-invest. Environmental policy tools such as regulation, standardisation and “green procurement” as well as fiscal and pricing policies need to be combined with technology policy in driving the development of the key technologies that will underpin sustainable growth in OECD countries.

INTRODUCTION

Technology foresight activities have proliferated in the OECD area in the present decade as the increasing importance of new technologies for industrial competitiveness and in achieving social objectives has been recognised. They are also related to the need to set research priorities under current public expenditure constraints and the increasing cost of research and development for complex and diverse contemporary technologies. Through foresight exercises, governments and industries can identify important new technologies and target resources for their development.

Technology foresight can be defined as "*systematic* attempts to look into the *longer-term* future of science, technology, economy and society with a view to identifying *emerging generic technologies* likely to yield the greatest *economic and/or social benefits*" (Martin, 1996). The longer-term future normally means a typical horizon of ten years, but can range between five and thirty years. Foresight exercises involve balancing "science/technology push" with "market pull" to identify technologies which are still at a pre-competitive stage of development, and which, therefore, legitimise government support. Attention is given not only to the industrial and economic impacts of new technologies but also to social benefits including effects on the environment.

Many foresight exercises attempt not only to identify *technologies* of the future, but also to foresee broad *socio-economic trends,* including trends related to the environment. These trends, in turn, generate certain types of needs to be fulfilled by developments in science and technology. Most OECD governments identify the creation of a sustainable socio-economic system as an important future trend towards which research and development should be geared. While technology cannot provide all the solutions, it is nonetheless a key constituent of the means that need to be harnessed to achieve sustainability objectives. Strategic thinking is necessary to develop coherent research programmes for environmental technologies that can play a crucial role in sustainable development. It is the role of technology policy to match what is possible and what is desirable in order to achieve environmental objectives. Technology foresight is a tool which can be used to orient research and development towards sustainable development objectives.

This paper surveys and compares the environmental issues as they appear in the foresight activities of various OECD countries. The survey is selective and based on some major government foresight initiatives launched in this decade.

ENVIRONMENTAL TECHNOLOGIES FOR THE FUTURE

Although many foresight studies include environment as a technology field, environmental technology is not a discipline-oriented category like medicine or particle physics. It is not an enabling technology like information or biotechnology. And it is not a distinct, discrete technology like advanced materials or nanotechnology. It is a technology defined by its *objective:* protecting the environment. When a technology is developed or applied with that objective, whether it be information technology, biotechnology or materials or process technology, it becomes environmental technology. Some technology areas, such as energy, are by their nature closely linked to environmental issues. Advances in technology areas that appear unrelated to environmental applications may in the future have significant implications for the protection of the environment. Environmental technology is, by definition, diffuse and can be part of any established technological area.

Predictions regarding the important environmental technologies of the future made by the most recent technology foresight surveys in OECD countries are described in subsequent parts of this paper. While these vary by country and by foresight exercises within countries, certain common technological themes relevant for sustainable development objectives emerge. These point to a range of diverse technologies in different fields and of varied types. A “consensus list” of important environmental technologies for the future would include the following:

Advanced sensors. Technological advances in sensors are critical for addressing both local and global environmental problems. Sensors will be used to monitor air and water quality as well as global changes in the climate, stratospheric ozone layer, marine environment and varied ecosystems.

Biotechnology. Biotechnology holds vast potential for sustainable development. Bio-processes can reduce pollutants from manufacturing; micro-organisms can aid in soil remediation; biodegradable materials will cut down on waste; and agrogenetics can limit adverse impacts from pesticides and other chemicals in agriculture.

Clean car technologies. Technologies that may make the car of the future more sustainable include alternative batteries, lightweight materials, direct injection engines, fuel cells and enhanced recyclability - all leading to lower fuel consumption and reduced emissions.

Product recycling. New production management techniques such as life cycle assessment and extended producer responsibility will be taken seriously in product design so as to facilitate recycling of consumer goods and manufacturing inputs. This will require advances in materials technologies and new techniques to recover and reuse natural resources.

Smart water treatment. New membrane technologies and biological treatments will be able to purify wastewater by removing organic compounds and may lead to community or home-based water treatment units.

Smart waste treatment. Approaches to reducing municipal waste and cleaning up hazardous waste will be based on new enzymes, catalysts, bioprocesses and other advanced techniques.

Cleaner industrial processes and micro-manufacturing. Industrial processes of the future will use fewer materials and less energy and produce less waste and hazardous emissions through the use of advanced biological and chemical catalysts, advanced separation and energy-efficient technologies. Radically cleaner processes may eventually use micro-technologies to produce a wide range of products from chemicals to energy in decentralised production units with reduced environmental impacts.

Renewables and newer energy technologies. Use of solar and wind power, biomass and hydrogen as well as cleaner coal technologies and more efficient conversion systems, such as combined heat and power generation, will grow in importance. Improved power storage and transmission technology such as flywheels and superconductivity will radically improve energy efficiency.

Photovoltaics. As one of the most promising renewable energy sources, photovoltaics will see more widespread use when technologies are developed to improve conversion efficiency and cost performance and applied in buildings, automobiles and decentralised power units.

FORESIGHT METHODOLOGIES AND THE ENVIRONMENT

As part of their methodology, technology foresight studies undertaken in the 1990s have attached greater significance to the environmental dimension. Some foresight exercises, notably in the Netherlands, have been specifically devoted to environmental and sustainable development issues. In several foresight studies, environment has been highlighted as a "criterion of importance" for ranking various technologies. This is a relatively recent phenomenon. Throughout the 1980s, criteria such as "economic growth", "technological competitiveness", "market size" and "national defence" were dominant. Some recent Delphi surveys have adopted environmental criteria in the broad assessment of the importance of the survey topics. In addition, the broader socio-economic trends featured in foresight studies have recently included environmental changes, such as the effects of global warming.

The technology foresight undertaken in the OECD countries today evolved from the technology forecasting conducted in the US defence sector in the 1950s and 1960s, where important foresight tools such as the Delphi survey and scenario analysis were developed. These methodologies remain key tools of current foresight activities. The Delphi method has been taken up in the Japanese government's forecasting exercise, the only foresight activity which has been conducted every five years since 1970. In other countries, in the second half of the 1980s, interest shifted towards broader foresight or *prospective*. Whereas the technological forecasting approach assumes the existence of a single future, to be predicted as accurately as possible by forecasters, the foresight approach assumes the existence of many possible futures, whose realisation depends on choices made today. Therefore, compared to forecasting, foresight "involves a more 'active' attitude towards the future" (Martin, 1996).

Since the 1980s, the newer foresight approach has gained in popularity, and its methodology and procedures have become more elaborate and diversified. In the current flourishing of technology foresight exercises, a vast array of methodologies are used. There are still considerable methodological problems for comparing various studies because of differences in terms of size, disaggregation, methodology and relevance (or in some cases, the absence or loose application of criteria and methodology), or because of the lack of technological details and comprehensiveness of assessments and recommendations for technology policy (Grupp, 1996).

Rather than reviewing and comparing methodologies and the context of foresight programmes (which has been done elsewhere, see Grupp *et al.*, 1998; Mogee, 1997; Gavigan and Cahill, 1997), it suffices for present purposes to note that recent foresight studies are broadly of three types:

- Studies based on and centring around a large-scale Delphi survey.
- Critical technologies studies.
- Consultation-based studies which in many cases integrate the critical technologies and/or Delphi survey approaches.

Despite the active use of methods used by others, foresight studies tend to be unique, with the method and the questionnaires (in the case of Delphi surveys) reflecting the specific research and innovation system and interests of the country being studied. Moreover, each study builds on and modifies past studies from other countries. In the process, the original technological forecasting methodologies become part of broader foresight exercises which include other activities such as panels and critical or key technology listings.

Many governments attach importance to the process involved in a technology foresight exercise. The interactions generate important feedback for researchers and policy makers, and this process, in which "one comes to a better understanding of the forces shaping the long-term future" (Martin and Irvine, 1989), leads to consensus building among experts and policy makers. Interaction and an active attitude towards the future characterise recent foresight exercises in the OECD area.

Foresight studies also differ in the way in which they are connected to the policy and the research system, in their objectives, in the degree to which they address broader socio-economic factors that drive developments in research, and finally in the ways in which they seek to gain access to and process experts' views. Objectives may range from stimulation of debate, to forming networks of innovators, to setting priorities for science and technology (Georghiou, 1996). In any case, these studies are efforts to cross disciplinary and institutional barriers to gain insight about possible and desirable future research as well as socio-economic developments and to generate consensus through a process involving a large number of experts and administrators.

Studies based on Delphi surveys

The Delphi survey method is designed to identify consensus and disagreements within large expert groups. In this method, a small group of experts formulates a list of technological developments, including broader technology-related socio-economic trends, or "topics", for the questionnaire which is sent to a large group of experts (panellists) who are asked to rate each topic on several measures, including its degree of importance, its expected date of realisation, constraints on realisation, and the need for international co-operation. Survey "rounds" are repeated and previous round results circulated to allow experts to reconsider their assessments. Final results are presented as statistics that include the opinion of the entire group. By conducting multiple rounds of surveys in which the results of the previous round are revealed to respondents, a consensus-building process is generated. It is used for relatively long-range forecasting of 20 to 30 years. Although there are some methodological problems, notably in the way the topics are generated and the time and costs involved, this remains one of the most widely used foresight methodologies (Mogee, 1997; Grupp, 1996).

Japan is the only country which has systematically and periodically conducted a Delphi survey since the 1970s. A forecast reliability survey based on the first survey (1971) was conducted in 1991, and results showed that about two-thirds of the survey topics were in fact fully or partially realised. This has given the Delphi method a level of reliability sufficient to form the basis of long-term R&D strategies (Kuwahara, 1996). In this decade, both Germany and France conducted Delphi surveys modelled on the fifth Japanese survey conducted in 1991. The results showed fairly remarkable agreement as to the importance and the timing of realisation of survey topics. Japan and Germany also designed and conducted a smaller-scale mini-Delphi survey for the purpose of developing an international survey methodology in 1994; the results also demonstrated close agreement. This has led experts to conclude that technology foresight based on the Delphi approach can be used consistently across countries and is not too susceptible to national influences (Martin, 1996; Grupp, 1996).

Japan: Fifth Delphi Survey

This survey was conducted in 1991 for a forecasting period to 2020. The aim was to gain an overview of important innovation trends in science and technology and to provide information to government and industry for formulating science and technology policy. A total of 1 149 topics were classified into 16 technological areas by a steering committee and 13 subcommittees organised by NISTEP. The response rate was about 80% in the two rounds. The general results showed the following: *1)* the fields of environment and life science had the highest percentage of topics (50%) for which a majority of respondents attached a high level of importance; and *2)* topics with a high level of importance were related to a healthy and secure lifestyle, which involves the preservation of the environment, conquest of diseases and disaster prevention.

In addition, the survey covered topics whose "relationship with environmental issues is regarded as important". This concerned about 19% of the topics of the survey questionnaire. The survey took the position that technologies relevant to environmental problems include not only those that *directly* but also those that *indirectly* solve environmental problems. In addition, some environmental issues, such as measures for global warming, would require combining technologies not only in the environment area but also energy, production, materials and processing, outer space, as well as marine and earth sciences to arrive at elucidation, monitoring and effective countermeasures (Kagakugijutsu Seisaku Kenkyusho, 1992).

Therefore, the environmental category was defined to include technologies that: *1)* are related to measurement, monitoring and prediction of environmental changes, and the elucidation of principles and mechanisms of environmental changes; *2)* technologies that contribute directly to solving environmental problems, including pollution prevention, control and remediation technologies; and *3)* "indirect" technologies whose main objective is not the environment but the use of which would also contribute to the solving of environmental problems. In concrete terms, this means topics related to global environmental issues (ozone layer depletion, global warming, acid rain, marine pollution, destruction of tropical rain forests, desertification, loss of biodiversity) as well as conventional and local pollution issues (atmospheric and water pollution, noise, wastes and destruction of natural ecosystems).

More than 80% of the respondents attached high importance to the environmental technologies listed in **Box 1**. Some of these were indirect countermeasure technologies such as energy conservation and development of alternative energy sources. There are topics on photovoltaics and the electric car, for which Japan is considered to be more advanced than other countries. Some basic technologies deal with monitoring and global environmental changes. Seventeen of these technologies are to be realised by 2010 and reflect the urgency of environmental needs. As for constraints on realisation, a majority (169) of technologies are believed to face technical constraints and, to a lesser extent, cost (97) and funding (44) constraints. Institutional, cultural, human resource and research system constraints were considered insignificant.

Box 1. Highest ranked environmental technologies in the fifth Japanese Delphi

- Technologies that will eliminate NOx and other pollutants that cause today's air pollution.
- Technologies for CO_2 fixation, artificial photosynthesis, treatment of hazardous wastes and prevention of desertification.
- Development of room-temperature superconducting materials.
- Development of a safety system for industrial and (nuclear) power plants which prevents destruction of plants by earthquakes.
- Technologies for segregating valuable substances in urban refuse for their retrieval.
- Technology to transform solar energy into biochemical energy.
- Waste re-use technology that reduces municipal waste by half.
- Safe and efficient decommissioning of commercial nuclear power plants.
- Technology to treat solid highly radioactive waste.
- Product recycling technology.
- CFC substitutes which do not deplete the ozone layer or contribute to global warming.
- Faster speed-train tracks (300 km/h) and an environmentally acceptable *shinkansen* train.
- Photovoltaic cells with more than 50% conversion efficiency.
- Dryness and salt-resistant plant strains to prevent desertification.
- Low emission technology (NOx emission of 0.1-0.2 g/km) for automobiles.
- Biodegradable packaging material.

Source: Kagakugijutsu Seisaku Kenkyusho (1992).

Germany: Delphi I

Interest in technology foresight developed rapidly in Germany in the early 1990s because of reunification and the tasks involved in restructuring a former socialist economy, as well as the budget constraints resulting from reunification and the worldwide economic recession (Grupp, 1996). Thus, the first Delphi survey was conducted in 1992. The exercise was modelled closely on the Japanese Delphi survey and conducted a year after the fifth Japanese Delphi survey. The discussion of the results of the German survey below is based on analysis and detailed comparison of the Japanese and the German results (NISTEP, 1994; Cuhls and Kuwahara, 1994).

Compared to the fifth survey in Japan, the response rate in the first round of the German survey was low (30%). This may have been attributable to such factors as lack of experience and as yet limited access to the former East Germany. The second-round response rate was comparable to that of the Japanese survey. The composition of respondents was similar, with one-third from universities, one-third from industry and one-third from government laboratories. Japanese Delphi topics were translated into German and used; those that did not apply in the German context were excluded. This resulted in 1 146 topics.

Overall results showed fairly strong similarities, especially in the time for realisation of the topics. In both surveys, the index of importance was highest in three technology areas one of which was the environment. The other two were medical care/health and life sciences. Other environmentally relevant technology areas with an average or higher than average index of importance in both countries were urbanisation and construction, marine and Earth science and energy. The forecast realisation time for technologies in the environment area and in other environment-relevant areas (materials and processing, marine and Earth science, mineral and water resources, energy, agriculture, forestry and fisheries, production, urbanisation and construction, and transportation) are similar. Most of these technologies are forecast to be realised in the medium term, between 2005 and 2009. Topics in marine and Earth sciences and urbanisation and construction are expected to be realised before 2005, and most topics in the energy area are forecast to be realised slightly later, towards 2010.

The list of the ten most important technologies in the German survey includes five environmentally relevant technologies, three of which had an importance index of more than 80 in the Japanese survey (**Box 2**). On the other hand, the two environmentally relevant topics in the top ten in the Japanese survey were rated with an importance index of 95 in Germany. These were: *1)* technologies that will eliminate NOx and other air pollutants; and *2)* technologies for global environmental preservation, including absorbing carbon dioxide (CO_2), artificial photosynthesis, turning waste into harmless substances and preventing desertification.

Box 2. Highest ranked environmental technologies in the German Delphi I

- Planning and construction technology enabling new urban development or urban redevelopment in harmony with the natural environment.
- Waste recycling technology enabling the amount of city waste to be reduced to half its current level.
- Technologies for utilising natural energy leading to successful heat balancing of the Earth.
- Technologies for effectively using energies such as extended heat storage of natural energies, leading to the dissemination of energy-independent buildings and houses.
- Cars with extremely low fuel consumption for the same interior size owing to reduced weight achieved by significant introduction of new materials such as ceramics, aluminium and resins and improved output achieved by higher engine efficiency (*e.g.* the use of 2-cycle, direct-injection engines).

Source: Cuhls and Kuwahara (1994).

Japan-Germany mini-Delphi survey

One outcome of the first German Delphi survey was a joint Japanese-German undertaking in which the mini-Delphi method was designed. Topics were jointly created by a committee of experts from the two countries and the survey was carried out simultaneously in both countries. The results were published in Japanese and German (Kuwahara *et al*., 1995). This was the first attempt to develop an international technology foresight methodology. The technology areas, as well as the range of topics in each area, were narrowed to four technology areas (with two sub-areas in each) and 120 topics. However, a provision was made in the first round for respondents to suggest other topics they considered important. As a result, the number of topics increased to 132 in the second round. Assessment criteria were the contribution to the development of: *1)* science and technology; *2)* the economy; *3)* the environment; *4)* developing countries; and *5)* society.

The results of the assessment of “importance for the environment” revealed that technologies in the areas of photovoltaics, waste treatment and global climate change received high ratings in both countries. Technologies in the areas of superconductivity, nanotechnology and artificial intelligence were rated at about average level of importance. Topics that received the highest ratings in both countries (index of more than 90) were: *1)* CFC substitutes; *2)* soil remediation by the use of micro-organisms; *3)* renewable energy sources; *4)* technologies for monitoring pollutants in the atmosphere and water; and *5)* residential photovoltaic systems.

Looking at results in the sub-area of waste treatment, there was fairly close agreement between the two surveys in the assessment of importance for environmental amelioration. Bioremediation, recycling systems and the development of environmentally compatible materials are considered important by experts in both countries. Most topics in this sub-area are forecast to be realised between 2002 and 2017. As for topics in the global climate change sub-area, both countries attached highest importance in the area of environmental amelioration to CFC substitutes and curbing of CO_2 emissions.

French Delphi

France is another country which has conducted a Delphi survey according to the Japanese model in this decade. The French exercise arose "from a recognition of the need to improve the technological vision of the government and to provide a more systematic approach to priority setting" (Martin, 1996). France had accumulated experience with *prospective* scenarios, but little with Delphi. This exercise, therefore, was launched "on an experimental basis" and viewed "more as the study of fledgling technological dynamics and the clash of major global trends than as an exercise in prediction" (Quévreux, 1996). For this survey, technology areas except for "life and culture" of the Japanese survey were used; however, topics were translated from the German questionnaire. The document compiling the results was published in 1995 (*Ministère de l'Éducation, de la Science et de la Recherche,* 1995).

The results for environmentally relevant topics agreed well with both the Japanese and the German surveys, although the time horizon tended to be a bit further off. In any case, environmental innovations are predicted to be implemented in the medium- to long-term future. In France, topics in the environment area were rated to be of highest importance along with life and medical sciences. Highest priority was for the provision of standardised measurement and information systems for the control of harmful substances. Other environment-relevant technology areas (energy, marine and Earth sciences, resources, and materials and production) were rated as of medium importance.

Japan: sixth Delphi survey

This survey, conducted in 1996, narrowed and redefined technology areas to 14 by: *1)* dividing "information and electronics" into "information" and "electronics"; *2)* combining "mineral and water resources" and "energy" into "resources and energy"; and *3)* removing "particles" and "lifestyle and culture" as technology areas and incorporating topics in other areas. A total of 1 072 topics were surveyed (380 topics from the previous survey, 233 modified topics and 459 new topics). The same criteria were used for a forecast period up to 2025. The response rates were 87% and 85%, respectively, in the first and second rounds. Comparing the topics in the fifth and the sixth surveys, many new topics are found in electronics and information technology areas whereas environmentally relevant areas of "environment", "marine and Earth science", and "resources and energy" include relatively fewer new topics. This may mean that in the present phase, the pace of innovation in information and electronics is very rapid, and that many new and important topics arise within a relatively short period of five years, whereas in environmentally relevant areas, topics recognised as important five years ago largely remain unrealised (Kikuta, 1998). While the basic nature of the research needed and the complexity of topics in environmentally relevant areas may explain this lag in part, the weakness of the market pull for environmental technologies, in comparison with technologies in information and electronics, may well be a major factor slowing the pace of research and innovation in the environmental area.

In the assessment of importance, topics in the environment area received the highest rating, with an index of 72.0, while the average for all topics was 62.1. Among the 100 topics with the highest ratings, 25 were environment-related topics and 11 were new energy topics. Compared to the fifth survey, there are more technologies related to recycling and photovoltaics and fewer relating to global environment. These technologies are listed according to their importance in **Box 3**.

Box 3. Highest ranked environmental technologies in the sixth Japanese Delphi Survey (expected date of realisation in parentheses)

- Non-fossil energy sources (wind, geothermal, solar and waste heat) in all areas of life including household, industry and transportation. (2018)
- Solar cells which make the cost of power generation facilities less than 100 yen/watt. (2012)
- Recycling systems which make it possible to recycle most used materials by establishing manufacturers' legal responsibilities for collection and disposal of disused products. (2012)
- Solar cells capable of maintaining 15% efficiency for at least 10 years without light convergence. (2010)
- Technology for decommissioning of commercial nuclear power plants. (2009)
- Multi-layer solar cells with a conversion efficiency of more than 50%. (2016)
- Large-area amorphous silicon solar cells with a conversion efficiency of more than 20%. (2011)
- Green product design concepts that encourage recycling and re-use. (2007)
- Plastics recycling technology. (2007)

Source: NISTEP (1997).

Germany: Delphi 98

In 1995, the German BMBF decided to launch the second Delphi survey. This time, although some topics were worked out in co-operation with NISTEP, the survey was designed independently in Germany. The steering committee chose 1 070 topics covering 12 technology areas, which they thought the most important areas for future innovation; the survey, undertaken in 1997, involved 7 000 experts, and the results were published in 1998 (Fraunhofer Institute and BMBF, 1998). The response rate was 29% in the first round and 75% in the second (1998).

Based on the results, the steering committee presented 19 megatrends that will influence science and technology, of which three were related to environmental issues and give a rather morose outlook for the future:

- The worldwide scarcity of fossil fuels will oblige rationing energy consumption for private households.
- Increasing environmental problems will negatively affect the health of most people.
- Climate change will lead to depopulation in wide regions.

The survey topics were assessed for their importance for the economy and employment, society, the environment and science. The survey topics that were rated as of high general importance were grouped according to the time horizon for realisation (short, medium and long term) into nine technology categories of which three are environment-related: product recycling and sustainable agriculture (medium term), new energy sources and potential for saving energy (long term), and technology for global management of environment (long term). Examples of important technologies (or *theses* as they are termed in the German survey) in each category are shown in **Box 4**.

Box 4. Highest ranked environmental technologies in the German Delphi II

Product recycling: Manufacturers of consumer goods with long service lives will be legally obliged to accept the return of their goods at the end of their service life and dispose of them, resulting in a recycling system that includes planning, production, collection and recycling or re-use, with the aid of which a practically completely closed material cycle can be achieved.

New energy sources: The proportion of renewable energy used to generate electricity (except hydroelectric power) in Germany will exceed 10% (from today's level of about 0.5%). Multi-layer or laminate solar cells capable of achieving energy conversion performance levels of more than 50% will become practical. System costs for network-coupled photovoltaic systems will drop below 4 000DEM/kWh (currently 15 000DEM/kWh).

Global environmental management: Ecosystem research on closed systems (biosphere) will improve our understanding of the global ecosystem to the point where a global framework of basic conditions for human survival can be created. Techniques to landscape deserts will be applied throughout the world to stop desertification. Drought- and salt-resistant strains of agricultural plants will be developed with the aid of biotechnology. These plants will be able to produce high yields, even in areas where the water table is threatened by salinisation. Cultivation in biomass will reduce the water requirement for agricultural plants.

Source: Fraunhofer Institute and BMBF (1998).

United Kingdom: Technology Foresight Programme

Because it is one of the most comprehensive and interactive foresight initiatives, the UK foresight programme is better categorised as a consultation-based study. However, it is discussed here because the programme integrated a major Delphi survey whose results may be compared with other Delphi surveys. The UK Technology Foresight Programme was launched in 1993 to improve the competitiveness of the UK economy and enhance the quality of life by bringing together business, the science base and government to identify and respond to emerging opportunities in markets and technologies and to inform decisions on the balance and direction of publicly funded science and technology. The catalysing function of foresight to exploit the science base for industrial competitiveness by creating and consolidating networks between these sectors was particularly important. A decision was made to make this programme less technology-driven and more market-oriented than foresight programmes in other countries. The Steering Committee set up panels in 15 technology areas including three service sectors which are not found in other programmes based on the Delphi survey method.

In the main foresight phase, the panels constructed scenarios for their areas, identified key issues and trends and consulted with the relevant communities. Consultations took place through direct contact between panel members and organisations and individuals with an interest in the area. In this phase, a Delphi survey was conducted to "achieve a structured dialogue with the widest possible cross-section of experts in the country" and was used as a consultative instrument for the panels, with topics and issues generated by the panels (Georghiou, 1996). Each panel compiled the results of the main foresight phase reports. This formed the basis of the synthesis report of the steering group, which organised the panel recommendations into 27 generic science, engineering and technologies (SET) priorities under six themes, one of which was an environment-related "cleaner world". The cleaner world priorities included:

- *Clean processing technology*: to produce more efficient processes via waste minimisation, reduced emissions, discharges and solid wastes; interactions between regulatory systems and the science base; and integrated monitoring and control of pollution.

- *Energy technology:* including combustion, monitoring and control: air-breathing aircraft engines, the control and minimisation of emissions; maximising fuel efficiency; and storage and transmission technology.

- *Environmentally sustainable technology*: including alternative, sustainable energy technologies and resource conservation; energy-efficient machines and systems; social issues relating to energy usage; the marine environment; appropriate technologies for developing countries.

- *Product and manufacturing life cycle analysis*: including life cycle evaluation in relation to sustainable technologies, environmental impact, changing use and lifelong support, manufacturing evolution, product evolution and incremental improvement; disposal and decommissioning.

The generic science, engineering and technology priorities emerging from the synthesis of panel reports were further prioritised by: *1)* key topic areas; *2)* intermediate areas; and *3)* emerging areas. Environmentally sustainable technology was categorised as a key topic area for which the steering group "recognised that radical technological breakthroughs are unlikely but that incremental advance is both necessary and likely to further wealth creation objectives for decades to come". The other three were categorised as emerging topic areas and were "assessed as contributing to competitiveness and quality of life in a diverse array of industrial (and particularly manufacturing) settings" and that there is a "distinct possibility that the UK can gain a competitive advantage over other countries by designing environmentally friendly components into new products".

Foresight results were also used to determine the direction of government research spending. Moreover, a Foresight Challenge Fund was created to support projects reflecting foresight priorities on a partnership basis with industry. The environmental technology area includes a wide array of cross-disciplinary and cross-sectoral technologies. The Cleaner Technologies and Processes sub-panel recognised that the promotion of intersectoral and interdisciplinary research for environmentally sustainable technologies is the precise challenge presented to industry and the research community. The sub-panel also recognised that because the environment can be affected by almost any activity, there is a potentially limitless scope for relevant research geared towards environmental objectives (Foresight Natural Resources and Environment, 1998). Four broad areas of relevant research on environmental technologies were identified (**Box 5**).

Comparison of Delphi surveys

One attempt to synthesise the Delphi surveys conducted in the first half of 1990s identified topics where there was substantial agreement among the surveys conducted in Japan, Germany, France and the United Kingdom (Gavigan and Cahill, 1997). Key technologies were highlighted in the eight technology areas of information and communication technology, health and life sciences, construction (urbanisation issues), environment (global scale issues), energy (power generation issues), production (automation issues) (**Box 6**).

Box 5. Priority environmental research areas in the United Kingdom

1. ***Cleaner technologies, techniques, products and services***: 1) industrial process technologies that use less material and energy and produce less pollution and waste, including waste minimisation, water use minimisation, separation technologies, biotechnology processes to replace high-energy chemical and physical processes, energy-efficient processes, cleaner technology in heavy engineering and coal technologies; 2) new product/service technologies including life cycle analysis, recyclable products, miniaturisation and dematerialisation, approaches to sharing ownership and leasing; and 3) associated socio-economic research, including ways to stimulate innovation in these technologies.

2. ***Environmental technologies and services***: 1) environmental monitors/sensors (biosensors, robust sensors, etc.); 2) water and waste treatment technologies: recycling, separation technologies, sensors and control systems, small-scale decentralised water treatment plants, desalination, land/water bioremediation; 3) associated management and public policy tools such as charging, service management and risk and cost/benefit assessment.

3. ***Sectors with major environmental consequences***: 1) *energy sector:* more efficient batteries and fuel cells, renewable energy including biomass, wind and photovoltaic cells, cleaner coal technologies, carbon sequestration; 2) *transport sector:* lightweight cars and their recycling, increased engine efficiency and alternative fuels such as hydrogen and fuel cells, improved battery efficiency, telematics for more efficient navigation, alternative forms of car ownership and improved use of mass transport systems; 3) *agriculture*: use of crops for biomass for energy or feed stocks, soil quality maintenance, development of saline-tolerant crop species that require less water; 4) *construction:* less energy-intensive construction materials, decentralised water, sewage and power systems, use of “smart” materials and better design and planning techniques.

4. ***Basic areas that underpin environmental application***: biotechnology, materials, information and communication technology, biochemical/electrochemistry, environmental science, and the human dimension of sustainability.

Source: Foresight Natural Resources and Environment (1998).

Box 6. Highly ranked environmental technologies in four Delphi Surveys

Construction:

1. (Japan, Germany, France): Practical use of distributed type house co-generation, utilising fuel cells. (UK): Compact co-generation plant, using fuel cell technology, in widespread use in large commercial buildings.

2. (J-G-F): Widespread use of community level systems of non-table water supply for miscellaneous use based on sophisticated processing of wastewater in big cities. (UK): Practical use of community level wastewater treatment systems reduces demand on national and regional infrastructures.

3. (J-G-F): Advancement in technologies for effectively using energies such as heat storage of natural energies, leading to dissemination of energy-independent buildings and houses. (UK): Development of "aero" energy buildings that are independent of utilities and infrastructure.

Global environment:

1. (J-G-F): Completion of internationally unified and standardised environmental information based on worldwide monitoring of pollutants (air, water, etc.) and satellite communications. (UK): Practical use of enhanced integrated environmental measurements and monitoring techniques incorporating ground-based, ocean-based and satellite measurement systems, supercomputers and global communications.

2. (J-G-F): Possibility of an accurate forecast of the magnitude of climate change due to global warming at about 50 km mesh level all over the earth. (UK): Development of accurate climate change forecasts at both global and regional scale.

3. (J-G-F): Possibility of determining, with high accuracy, the inventory of greenhouse gases other than carbon dioxide for each generating source and each area. (UK): Development of comprehensive and accurate greenhouse gases inventories (national and global) to improve the quantification of the impact of climate change.

Power generation:

1. (J-G-F): Practical use of fast breeder reactor systems with an operation including the nuclear fuel cycle. (UK): First commercial use of a Fast reactor.

2. (J-G-F): Widespread use in industry of a power generator and other electrical equipment applying superconductivity. (UK): First commercial application of high-temperature superconductors for power applications.

3. (J-G-F): Widespread use of technologies that make it possible to treat and recycle wastes and the like at low cost by using biotechnologies and to collect energy sources such as methane. (UK): Widespread recovery of energy from waste materials.

Source: Gavigan and Cahill (1997).

Critical technologies studies

Another group of technology foresight studies is based on lists of critical technologies. These studies are usually generated using expert group discussion techniques. The selection of technologies is based on factors including importance for economic competitiveness, relevance for national security, contribution to the quality of life, and the potential for application in many industrial sectors. The methodological problems associated with this approach include the fact that there is no commonly accepted definition of what makes certain technologies critical, and that they involve relatively few people and identify technologies that are rather broad for policy decisions (Mogee, 1997; Martin, 1996). However, there have been numerous initiatives involving this type of foresight, partly because they tend to be more advantageous in terms of cost. Studies of this type do in fact demonstrate that wide-ranging technologies have relevance for environmental applications. Three major undertakings are discussed here: the German T21, the French 100 key technologies and the study by the US National Critical Technologies Panel.

Germany: T21

This exercise was undertaken along with the first Delphi survey and started in 1992. It aimed to identify technological trends and their possible commercial applications in the civilian sphere, with a time horizon of ten years, i.e. the start of the next century. A strict and transparent methodology was applied. It started by a selection of critical technologies, then, using relevance trees, the contributions of future technologies to solving societal, ecological and economic problems and bottlenecks were clarified. The project also aimed to mobilise for foresight purposes the in-house expertise of German research administrators by naming several *Projektträger* (programme operators), agencies mostly located in the national laboratories, to assist BMBF and the Fraunhofer Institute for Systems and Innovation Research, which was charged with the design and execution of the study. Representatives from these "programme operators" set up a task force and worked together on an assessment of critical technologies.

The initial selection of critical technologies produced a list of about 100 technologies which were then redefined and regrouped in bilateral and panel discussions, by "searching for relationships, areas of overlap and evidence of cross-fertilisation between scientific or technical lines of development previously regarded as unconnected" (Grupp, 1994). The exercise revealed technological overlaps and the blurring of borderlines between individual technologies and new disciplines being shaped outside classical research areas. The exercise considerably increased knowledge among the staff of the government agencies involved (Grupp, 1996).

The study first identified and grouped critical technologies under nine generic headings: advanced materials, nanotechnology, microelectronics, photonics, microsystems engineering, software and simulation, molecular electronics, cellular biotechnology, and production and management engineering. These technologies were then assessed as to the contributions they could make towards solutions in the following technology areas: construction, energy, food, medical, exploration and security of raw materials (including recycling), environmental and transport. Results showed that all generic technology areas could potentially make contributions to environmental technology. Most technologies in advanced materials and cellular biotechnology were potential contributors.

Some long-term perspectives on technology policy were developed. Emphasis was also placed on a form of technological development "which encourages wide-ranging participation by players from various sectors, and of varying size, and which leads to an open market with no specific centralised structure". This leads to "various starting points" for technology policy, one of which is to "set up framework conditions, especially legal regulations, which point technological development in the direction of sustainable development and the protection of scarce resources" (Grupp, 1994).

France: 100 key technologies

This exercise of the French Ministry of Industry undertaken at about the same time as the Delphi survey of the Ministry of Education, Science and Research had a specific industrial focus. It attempted to balance "market pull" and "technology push" for the purpose of identifying important technologies for French industries and assessing the position of the French industrial sector in these technologies. It also intended to identify priority areas of action, for a relatively short time horizon of ten to 15 years. It was designed to help French firms identify technological priorities and to be used as a strategic tool in the formulation of public technology policy. The programme started by setting up a steering committee composed of influential members of the government, university and industry research sectors, which first adopted nine criteria for selection of technologies.

The next step was to organise expert groups which met periodically (1993-94) and used the criteria to identify technologies in five “market pull” areas and five “technology push” areas. These were:

- *Market pull areas:* health and environment, services and communication, transport systems, consumer goods, housing and infrastructures.

- *Technology push areas*: life sciences, information technology, energy technology, “soft sciences” and production management techniques, materials and associated technologies.

At the end of this stage, from a total of 676 technologies, 136 were selected by the steering committee as being particularly important. In the third phase, the competitive position of the French industrial sector and the scientific lead of the French research sector in these technologies were assessed. The results were synthesised in the fourth phase to identify and characterise these technologies in terms of France’s relative strengths, attractive attributes and conditions of success. In the end, 105 technologies were labelled “key technologies” including the environment-related technologies listed in **Box 7**.

US National Critical Technologies Panel

The US National Critical Technologies Panel has been conducting critical technologies studies every two years since 1991. The purpose is to identify the specific technologies that constitute priorities for the federal R&D effort. “Critical technologies” are defined as those essential for “developing and furthering long-term national security or economic prosperity”. Technology is defined to exclude much of basic science, which is directed at pure understanding of natural phenomena, but includes “knowledge built on scientific understanding and knowledge acquired through experimentation or accident”.

The most recent process started with a candidate list which included technologies from the first report in 1991 as well as lists of critical technologies prepared by other government agencies. Technology experts were consulted so as to include knowledge of specific technologies and applications. The final list was created with participation from the committees of the National Science and Technology Council and approved by the National Critical Technologies Review Group which includes members of the President’s Committee of Advisors on Science and Technology. The resulting report presented 27 national critical technology areas in seven technology categories. It includes information about the state of development in each technology and the United States’ competitive position relative to worldwide leading-edge technology developments. **Box 8** lists environment-related technologies assessed to be critical for US economic prosperity.

Consultation-based studies

Some foresight studies involve wide and extensive consultation with experts to determine important technological trends. This is an approach which attaches importance to the interactive process and the creation of a common vision. The studies examined here are those of the Australian Science and Technology Council and several exercises conducted in the Netherlands.

Box 7. Critical environmental technologies in France

Health and environment area:

High yield crops for use as biofuels.
Genetic modification of plants.
Decontamination and remediation of polluted soil.
Biological purification of water.
Radioactive waste treatment and disposal.
Final treatment and disposal of hazardous wastes.
Measurement and monitoring of environmental pollution (air, water, solid wastes).
Modelling the impact of industrial pollution.
Cleaning without using hazardous substances (*e.g.* CFCs).
Recycling of polymers (plastics).
Treatment of urban wastes.
Treatment and quality control of drinking water.
Collection, stocking and compression of urban wastes.
Using *filières transversales* for waste disposal.

Transport area:

Improving the recyclability of cars.
Batteries for electric cars.
Traffic flow control and management system.
Reducing the fuel consumption of motors.
Clean combustion engine.
Reduction of the weight of cars by using lightweight materials.
Reducing noise of aeroplanes and rapid trains.
Reducing the noise of automobiles.

Materials:

Intelligent materials.
Materials resistant to high temperatures.

Energy area:

Biomass conversion.
Clean and safe nuclear energy.
Photovoltaics.

Housing and infrastructures:

Management of water resources.

Production, instruments and measuring:

Intelligent sensors.
Catalysts.
Continuous processing in steel.
Membrane separation processes.

Source: Ministère de l'Industrie (DGSI) (1996).

Box 8. Critical environmental technologies in the United States

Energy:

- Energy efficiency: building technologies (super windows, modular utility components, energy-efficient lighting, appliances, advanced building management) and non-IC propulsion systems.

- Energy storage, conditioning, distribution and transmission: includes sub-areas of advanced batteries, power electronics and capacitors.

- Improved generation: includes sub-areas of gas turbines (combustion design, high-temperature materials), fuel cells, next generation nuclear reactors, power supplies, and renewable energy (solar thermal power technologies, photovoltaics, wind turbines, biomass fuels).

Environmental quality:

- Monitoring and assessment: integrated environmental monitoring (sensors, software, networking, simulation), and remote assessment of biosystems.

- Pollution control: includes specific technologies of physical separation, component separation, chemical transformation, biological agent separation, waste elimination.

- Remediation and restoration: remediation and restoration (soil washing, thermal desorption, composting, electrochemical separation, supercritical water oxidation, recovery of spilled oil and other hazardous substances); bioremediation; nuclear wastes storage, treatment and separation.

Living systems:

- Biotechnology: bioprocessing (for chemicals production and mineral extraction), recombinant DNA technologies (for modification of agricultural species).

- Agriculture and food technologies: sustainable agricultural production (identification, preservation and utilisation of genetic resources, ecosystem management).

Manufacturing:

- Continuous materials processing: catalysts, pollution avoidance (through process design strategies, improved processes, design for the environment, industrial ecology).

Materials:

- Alloys, ceramic materials, composites, electronic materials, photonic materials, and superconductors.

Transportation:

- Propulsion and power: electrically powered vehicles (energy storage technologies).

- Systems integration: intelligent transportation systems (sensors, networks, software, satellite navigation).

Source: US National Critical Technologies Panel (1995).

Australia: ASTEC study

Council (ASTEC), in *Matching Science and Technology to Future Needs 2010* (ASTEC, 1996), attempted to examine Australia's key future needs and opportunities and ways to match scientific and technological developments to these needs through an extensive consultative process, with the objective of improving Australia's long-term economic competitiveness and social and environmental well-being.

The exercise consisted of a set of four parallel activities. In the first phase, supply and demand issues in science and technology facing Australia were examined through extensive consultations in workshops and roundtables. The exercise identified key issues for Australia to 2010 in six areas: *1)* innovation and entrepreneurship, *2)* a technologically literate society, *3)* capturing opportunities from globalisation, *4)* sustaining the natural environment, *5)* continuous improvement in community well-being, and *6)* building a forward-looking science and technology system. In the second phase, ASTEC formed partnerships with other organisations which carried out foresight studies in specific areas: health, life cycle of urban water, shipping, youth, and information and communication technologies.

The third phase reviewed other foresight exercises in Australia and in other countries. In the fourth phase, ASTEC commissioned a study of the impact of science and technology on economic growth as a means of assisting in ranking the priority of science and technology issues. These activities led to the identification of key forces for change, which formed the basis for the strategy to be recommended to the government. Also, as a part of the study, ASTEC identified six generic "critical technology" areas for the 21st century: *1)* environment (including energy); *2)* transportation; *3)* information and communications technology and electronics; *4)* genetics and biotechnology; *5)* manufacturing and precision and control in management; and *6)* materials.

Initial consultations with industry identified environmental sustainability, including sustainable energy use, as a dominant theme in their forward planning. Other opinions also attached importance to environmental issues, ranging from the "role of the environment in uniting the community", to "alternative energies and the integration of economic and environmental issues". These led to ASTEC's identification of "the need to sustain our natural environment" as one of six key issues. In the Partnerships exercise, the Urban Water Partnership recognised the importance of environmental factors in creating safe and secure water supply and treatment systems. The Independent Studies exercise revealed that high importance was attached to environmental issues and technologies in the foresight studies of other countries. Finally, as a result of the Economic Growth Consultancy, it was recognised that in order to integrate environment and economic growth, Australia needed to develop indicators for sustainable agriculture. This should link the three aspects of environment, economy and society and develop a system of resource accounting, which was identified as a priority area of action for the government.

The Netherlands

The Dutch government has carried out a number of foresight studies during the past decade. One was the Technology Foresight Experiment of the Ministry of Economic Affairs which studied scenarios to outline the applications potential of new or existing technologies in the Netherlands within the next five to ten years. The technologies examined were mechatronics, adhesives, chip cards matrix composites, signal processing, separation technology, production technology and embedded software. Of these technologies, the study on separation technology had environmental implications in that it emphasised the substantial potential of the technology to optimise production yields and eliminate environmental pollution.

One of the follow-up activities is the review of strategically important technologies for the Dutch economy in the medium term through interviews and consultation with experts in the private sector. Technology Radar relied on the results of a foresight study which was carried out by the Foresight Steering Committee of the Ministry of Education, Culture and Sciences and identified 15 technologies considered strategic for the Dutch economy. The process of selecting these technologies started with the creation of a combined list of technologies that were recognised as being of strategic importance from the foresight studies of other countries. The set was then narrowed to select those that were strategic for Dutch industries (Ministry of Economic Affairs, 1998). Key environment-related technologies included bioprocess technologies and energy-saving technologies.

The study attempted to identify research priorities for the longer-term time horizon of ten years or more. Objectives were to: *1)* stimulate the process of foresight in the research sector; and *2)* to formulate policy options for research on the basis of the results. The foresight process involved establishing a working dialogue between experts from both the supply and demand sides of research with a view to organise the Netherlands' national knowledge system so that future demand for knowledge could be satisfied. The steering committee was presented with a list of subjects for foresight studies which covered not only the areas of science, technology and engineering but also associated relevant social science and humanities areas. This was a distinctive feature of this study. As a result, 16 separate studies were undertaken, separate reports were prepared, and a synthesis report produced.

The study identified a number of "knowledge themes" for future research. With regard to the environment, these included "National Research Initiative Factor 4", which aimed to reduce environmental impacts by half, even if the nation's prosperity doubled and included the following elements:

- Promotion of energy research to reduce the price of renewable energy sources and to raise the level of energy efficiency by utilising gas technologies in households and businesses.

- Application of microsystem technology for the development of production technology and industrial process control and for the agriculture and medical sectors. Waste streams could be minimised by taking continuous measurements and by adopting more accurate production techniques.

- Technological, catalytic and biotechnological research focusing on processes which allow achieving the maximum level of purity in the end product and a minimum amount of residual product; chemistry research aimed at transforming those products which do not, or no longer, fulfil a function into raw materials which have an economic value.

- Development of sustainable industrial systems in agriculture. The options for both integrated and biological (ecological) industrial systems must be investigated. Multidisciplinary programmes focusing on the development of model systems based on biological, technological and socio-economic research are important here.

- Research into the ecological and socio-economic preconditions and the transformation process required for a sustainable economy (business strategies, consumer behaviour, infrastructure and technology) (Foresight Steering Committee, 1996).

None of the foresight studies discussed so far focused specifically on environmentally relevant technologies. One of the most recent foresight exercises in the Netherlands – The 81 Options: Technology for Sustainable Development – was undertaken with this focus. Rather than conducting a Delphi survey or organising consultation processes to define future technologies, the exercise started from the results of the foresight studies conducted in this decade both in the Netherlands and abroad. It identified

2 500 technologies. The positive or negative impact of the technologies was assessed in terms of: *1)* utilisation of fossil fuels; *2)* use of scarce raw materials; 3) emissions; and *4)* wastes. As a result, 81 “technology systems” were identified which had environmental relevance for the Netherlands in the 15 to 25 years to come (Weterings *et al*., 1997).

These technologies were then grouped into “clusters” in accordance with their function and technological interrelatedness (**Box 9**). The prospects of realising these technology systems were assessed according to three different scenarios of global economic development: 1) a *balanced growth scenario* which assumes a path towards “strong multipolar economic growth in which major progress is simultaneously made towards ecologically sustainable development” and which would attach high importance to technologies that “help raise the level of material productivity and energy conservation” on the global level; *2)* a *European renaissance scenario* which assumes a path that stresses European prosperity with environmental awareness mainly within the European sphere and with emphasis on technologies that reinforce the effectiveness of the economic infrastructure, such as information and communication technology; and *3)* a *global shift scenario* which assumes a shift in the centre of economic growth to the Pacific rim, with environmental awareness limited to the local level.

The study concluded that about 60 of these technology systems had a positive influence on the environmental efficiency of products, processes and activities through substitution of fossil energy by renewables, energy saving, emission and waste reduction, dematerialisation or reduction in use of raw materials. It found that the extent to which these technologies were developed and diffused depended on social trends as well as the supply of knowledge. Especially crucial were the price of energy and social willingness to change habits. The most important driving forces for achieving breakthroughs in environmentally efficient systems were a high level of technological dynamism and an articulated societal demand for such systems. On the other hand, for all clusters, the most significant obstacle was the price of fossil energy. Government policies should include measures to: *1)* stimulate R&D in these technology systems as well as their diffusion; *2)* stimulate demand for these technologies, including pricing measures which lower barriers to the introduction of new technologies; and *3)* avoid negative environmental effects through environmental regulations that effectively select out less efficient technologies and bring in newer more efficient ones.

Box 9. Important environmental technology clusters in the Netherlands

Energy Systems Cluster. This includes technology systems such as coal gasification, nuclear fission, new generation of photovoltaic cells, solar collectors, and wind energy, as well as new systems such as nuclear fusion, biomass as fuel, hydrogen as fuel and fuel cells.

New Materials Cluster: This includes technological systems which lead to substitution of currently used materials by biological materials (cultivation of biological raw materials, biotechnological crop improvement, packaging based on biological raw materials, alternative processes for preserving wood, wood-based composite and laminated building materials); new composites (metallic matrix composites, fibre-reinforced plastics, composites for lighter road vehicles, super-aircraft, supersonic aircraft, fast/light vessels, wood-based composite and laminated building materials); and new pigment or colouring systems (new water-based inks, substitution of heavy metals as pigments for construction ceramics, optimisation of textile treatment, low-solvent paints and lacquers).

Production Systems Cluster. This includes technology systems that contribute to more efficient use of fossil fuels and scarce raw materials as well as a reduction in waste and emissions, such as advanced separation, catalysis, design for environment, advanced water supply and water purification and industrial energy saving.

Information and Communication Systems Cluster. This includes technologies that have indirect environmental consequences. Increased use of domestic and business communication systems and teleshopping reduces the need for physical displacement. Intelligent navigation can improve traffic flow, thus reducing energy consumption. Use of information and communication systems enhances the shift from folio to non-folio, *i.e.* replacing paper, thus reducing waste.

Transport Systems Cluster. This includes technology systems that redesign existing technologies (super-aircraft, supersonic aircraft, fast/light vessels and new trains products and systems), make use of intermodal transport (intermodal goods transport, intermodal passenger transport/transfer stations), and the introduction of new infrastructure systems, the zeppelin and underground pipeline transport.

Source: Weterings *et al.* (1997).

CONCLUSIONS

Despite the divergence in structure of the technology foresight exercises reviewed here, the environment-related dimensions of these studies converge in certain respects. Sustainable development is generally viewed as a key future need which science and technology should address. Some foresight studies are exclusively concerned with the environment. All attach high importance to environment-related issues and the technologies that can help achieve sustainable development objectives. The Delphi surveys include the environment as a technology area, and they rate environment-related technologies as of higher importance than many others. Many foresight studies adopt relevance for improving the environment as a major criterion for selecting the technologies of the future.

The Delphi surveys emphasise that the time horizon for developing many emerging environment-related technologies is long, whereas it is short for information technologies. In part, this is because basic research is still needed and because the topics involved are complex. Perhaps more importantly, it is because the market pull for environmental technologies is weaker than that for information technologies. This points to the importance of focused research policy for developing environmental technologies and of a judicious combination of technology policy with environmental and fiscal policy tools to bring suitable innovations to the market more rapidly. The growing stress on global environmental issues reveals the need for better technologies for understanding and monitoring global-scale phenomena. It also underscores the need to strengthen long-term international S&T co-operation to assess, understand and track environmental changes such as global warming, desertification and atmospheric factors.

Foresight studies reveal that environmentally relevant technologies are very diffuse and found in many technological fields and categories. Moreover, technologies relevant for the environment are intertwined and interrelated. Enabling technologies such as information technology and biotechnology as well as advanced materials find application in many environment-related areas. Because of the diffuse nature of environmental technology, forging linkages between researchers in government, industry and universities is an important function of foresight activities. In view of the interdisciplinary nature of such technologies, network-building is crucial. Specific environment-oriented foresight exercises could help create networks of people who share a common view of ways to achieve sustainable development objectives.

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