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Special Issue on "Sustainable Development"

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on Sustainable Development

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

– to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
– to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
– to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

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FOREWORD

Prepared by the OECD Directorate for Science, Technology and Industry, the STI *Review*, published twice yearly, presents studies of interest to science, technology and industry policy makers and analysts, with particular emphasis on cross-country comparisons, quantitative descriptions of new trends and identification of recent and future policy problems. Because of the nature of OECD work, the STI *Review* explores structural and institutional change at global level as well as at regional, national and sub-national levels. Issues often focus on particular themes, such as surveys of firm-level innovation behaviour and technology-related employment problems.

This issue of the STI *Review* examines aspects of sustainable development related to industry and technology. The articles reflect the wide variety of research and analysis on policies and programmes to achieve sustainable development which is ongoing in various parts of the OECD. This research is also part of the OECD Three-year Project on Sustainable Development, a co-ordinated effort of the different Directorates and Agencies of the Organisation, which will yield a comprehensive report in June 2001. Particular attention is being given to the economics of sustainable development, including economic frameworks for technology and innovation. Governments must ensure that the parameters are set for encouraging industry investments in clean technology and environmental management strategies. Governments also contribute through financing the basic research that underlies innovation, developing and diffusing technology, and pursuing "green procurement".

The views expressed in this publication do not necessarily reflect those of the OECD or of its Member countries. The STI *Review* is published on the responsibility of the Secretary-General of the OECD.

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OVERVIEW

The concept of sustainable development originally derives from the scientific literature, where it implies the management of a natural resource in ways consistent with the preservation of its reproductive capacity. It has now acquired a broader meaning, implying that the objectives of increasing economic efficiency and material wealth must take into account social and environmental concerns within an overall policy framework. The OECD Three-year Project on Sustainable Development is an attempt to make the concept operational for public policies. It approaches sustainable development as a key economic issue, the response to which requires modifying economic incentives to incorporate environmental and social concerns.

A major obstacle to achieving sustainable economic development arises from the presence of external environmental costs and the lack of appropriate prices for many inputs as well as goods and services. The role of such market failures in discouraging investments in clean technologies is highlighted in the first two articles in this volume. The OECD *Working Group on Technology and Sustainable Development* summarises the results of over a year of study of the relationship between technology and sustainable development. Technology will be critical in meeting the needs of current and future generations and in de-linking economic growth from environmental degradation. However, appropriate technological change is not automatic. Market failures, including information and pricing failure, risk stifling rather than stimulating technologies that may enhance sustainable development. Governments must improve framework conditions so as to provide the right incentives and price signals to firms, and influence consumer awareness and behaviour with respect to environmental concerns.

Improving the signals involves making sure that existing prices better reflect the full marginal costs and benefits to society of different technical approaches. This partly depends on removing government subsidies, changing relative tax levels and reforming other inappropriate public policy interventions. For example, government subsidies (*e.g.* in energy) may stimulate overuse of inputs or overproduction and lock in prevailing and often inefficient technologies. Taxes and user charges for public goods (*e.g.* water, transport) may not cover public spending on infrastructure nor their health and environmental costs and may discourage investment in alternative approaches. In addition to getting the prices right, government policies in the areas of both environment and innovation could be better integrated to stimulate the development of clean technologies and more integrated approaches to pollution prevention.

This two-pronged approach – correct pricing combined with active technology programmes – is explored with respect to the energy sector by B*irol and* K*eppler*. Increasing energy efficiency is of particular importance given the commitment of most OECD countries under the Kyoto Protocol to reduce by 2012 their greenhouse gas emissions by an average 6% below the level of their emissions in 1990. Improvements to technological efficiency are key to decreasing energy intensity while maintaining economic growth. Enlightened use of economic instruments – in particular, fewer subsidies and higher taxes – could lead to more appropriate energy pricing and decreases in energy consumption. But this does not downplay the importance of public investments in research and technology development and diffusion, which are also essential to enhancing long-term energy efficiency.

According to F*ukasaku*, innovation is an important part of the industrial response to environmental regulation and can contribute to firm-level competitiveness. In this, there are parallels to new growth theory where innovation and induced technical change are important drivers of economic growth. The economic and social value system at the base of the current technological trajectory appears to be evolving towards greater internalisation of social costs, including environmental externalities. New patterns of growth based on structural factors including technology may be further strengthened if the underlying innovations are sustainable as well. Yet innovation for environmental sustainability presents a typical case of market and systemic failure where public policy interventions may be called for.

Greater use of biotechnology as a sustainable development tool depends on further research as well as on greater consumer acceptance, as described by G*riffiths and* W*ald*. The industrial applications of biotechnology have been relatively non-controversial, even though the food industry is a sector where biocatalysis is being introduced for the sake of cleaner production. Industrial biotechnology replaces traditional catalysts and transformation processes – many of which are very polluting – by newer, environmentally friendly ones based on living organisms. It aims at reducing production inputs, such as raw materials and energy, and at eliminating or at least reducing waste generation in sectors from pharmaceuticals to metals. Because industrial biotechnology can also enhance resource efficiency and lower costs in production, thus contributing to competitiveness, more industrial sectors are adopting this approach to increasing their sustainability.

The next articles demonstrate the value of specific types of government programmes when directed towards environmental aims. H*eaton* analyses environmental technology verification (ETV) programmes, which are relatively new and still primarily confined to North America. These government-funded programmes test new environmental technologies, demonstrate their contributions in different industrial processes and settings, and help them overcome initial regulatory hurdles. ETV schemes have proven a boon to technology vendors in the environmental goods and services industry, which is coming closer to being categorised and classified, as described by *Vickery and Iarrera*. The actual economic contributions of this new growth sector have been difficult to calculate due to measurement problems which are now being overcome in a joint statistical effort by the OECD and Eurostat.

Governments have a role not only in developing and diffusing clean technologies but also in becoming enlightened consumers of goods and services. *Eppel* advocates that governments set a good example to the private sector and the public through "green procurement". In work done for the Climate Technology Initiative (CTI), she examines how governments could direct their significant purchasing power towards climate-friendly technologies, leading to first-mover as well as market-scale effects. These are technologies which use renewable energy sources and achieve energy efficiencies. Public purchases of items from boilers and windows to computers and cars could be more environmentally correct. Governments will have difficulties advocating responsible environmental behaviour to others if they are not taking the same measures closer to home.

The role of industry and the public in the sustainable development process is more closely examined in the next articles. *Dearing* presents the view of the World Business Council for Sustainable Development on technology co-operation with developing countries. Older concepts of technology transfer have been replaced by an emphasis on capacity-building in these countries to increase their own ability to identify, adapt and implement clean technologies appropriate to their needs. The private sector can make a substantial contribution to technology diffusion worldwide through the investments it makes in these countries and the skills it helps to develop.

This is part of the growing sense of corporate social responsibility among firms, as explained by *Mega*. More enterprises are adopting environmental management strategies and making green investments both to get a jump on regulatory compliance and to improve their efficiency and competitiveness. Another influence is the growing number of corporate codes of conduct, such as the OECD Guidelines for Multinational Enterprises and the ICC Business Charter for Sustainable Development. These codes are appearing at the industry, national and international levels and can be developed either by governments or the private sector. However, it is unclear to what extent these codes are translated into deeds and reflect a real commitment to sustainable development beyond a public relations campaign.

It is difficult to see how standardised reporting by firms of the pollutants they are releasing into the environment – information which is shared with the public – can be good for public relations. Yet *Fenerol* explains how governments are adopting industrial pollutant reporting systems which can be either mandatory or voluntary. Data on pollutants are reported annually by source. This helps build an environmental database of potentially harmful releases to air, water and soil and is valuable to industrial planning as well as government monitoring. These systems, initiated in the United States, are founded on the concept of community right-to-know.

The role of consumers in sustainable development is the subject of the article by *Cantell and Ericsson*. Sustainable consumption is an important but oft-neglected element of sustainable development. Yet the paradigm shift to sustainable development won't be achieved without far-reaching changes in social attitudes towards goods consumed, waste disposed of, transport used, etc. Most consumers say they are willing to pay to protect the environment, sort their waste for recycling and shop in an environmentally sound way. But in reality they do little to change their consumption patterns. Governments are mounting educational campaigns and schemes such as eco-labelling to raise consumer awareness. More influential would be changes in relative prices for goods and services, to reflect their environmental costs and contributions, which could help steer consumers in the direction of sustainability.

Candice Stevens

TECHNOLOGY AND SUSTAINABLE DEVELOPMENT

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This article was prepared by the OECD Working Group on Technology and Sustainable Development and is excerpted from the 1999 Progress Report of the OECD Three-year Project on Sustainable Development.

I. INTRODUCTION

Technology is one of the topics being treated in the OECD Three-year Project on Sustainable Development, which involves most directorates of the OECD (*e.g.* Economics, Environment, Agriculture, Science and Technology), the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) in an effort to develop policy recommendations for Member governments for achieving sustainable development goals. The underlying objective of this horizontal effort is to achieve policy coherence in addressing sustainable development issues. There will be a series of interdisciplinary workshops and conferences as well as analytical reports. A policy report will be delivered to the OECD Ministerial Council Meeting in 2001.

The following are among the technology areas to be studied as part of the OECD Project on Sustainable Development: *i*) the concepts of eco-efficiency and resource efficiency and their relationship to sustainable development, including the development of indicators that can be applied to countries, sectors and technologies; *ii*) how innovation systems and the design of environmental policies and regulations can best provide the conditions and incentives needed to promote environment-related innovation; *iii*) specific technologies and their contributions to sustainable development, including nuclear power and biotechnology; *iv*) case studies of how enterprises incorporate environmental objectives into their management strategies, including investments in clean technologies; and *v*) means for facilitating international collaboration in research and development on environmental problems and technologies. The following article reflects OECD views on the role of technology and innovation in sustainable development as contained in the 1999 Progress Report to OECD Ministers (OECD, 1999*a*).

II. THE ROLE OF TECHNOLOGY

Technology is critical to securing sustainable development goals, in particular in de-linking economic growth, as measured by GDP, from environmental degradation and unsustainable resource use. Significant reductions in energy and materials intensity and polluting emissions will require technological advances in products and processes, as well as organisational and behavioural changes. These technologies can contribute to the improved performance and competitiveness of industry. Global environmental concerns – including loss of biodiversity, climate change, ozone layer depletion and desertification – will also require the best scientific and technical insights for assessment and solution.

However, appropriate technological change is not automatic. In traditional growth theories, new technology is an *exogenous variable* appearing from outside at the right time and right price. In reality, market failures in terms of information deficiencies and inappropriate pricing risk suffocating rather than stimulating technologies capable of enhancing sustainable development. Producers and consumers may lack knowledge about the environmental impacts of different products and activities. The prices of many goods and services often do not reflect resource use or environmental externalities. As a result, new substitutes tend to be more expensive than conventional technologies. The costs of developing new, clean technologies and integrated approaches are often high and the timeframes long. Where the benefits are more public than private, the result is insufficient industrial investment and inadequate technological innovation. Providing proper price signals would increase investment in clean technologies.

E*ndogenous growth theories* acknowledge that technological change occurs as a result of identifiable processes including corporate investment and public policies (Aghion and Howitt, 1997). Governments have an important role to play in getting the prices right and in providing a climate for environment-related innovation. The economic, legal and physical infrastructure is an important determinant of levels and patterns of research and development, institutional interactions, education and training, investment and finance, communications, etc. Market factors, such as consumption trends, and government regulation are important influences on the innovation climate. In general, the design of framework conditions for sustainable development should be set from the perspective of balancing increases in material welfare with long-term environmental and social challenges and the actions needed to address them.

Governments have a more direct role in developing and diffusing technology for sustainable development and in the financing of the basic research that underlies innovation. Technology development has become the focus of an increasing number of public research partnerships with the private sector. Governments may also act to ensure that existing valuable technologies are more widely used. For example, the technologies needed to meet the Kyoto Protocol targets for greenhouse gas reduction are mostly available today, but may require government action to see that they are much more widely deployed (Box 1). At the international level, governments need to work together to promote the use of clean technologies on a global scale as well as to address global-scale ecological issues.

Box 1. **Energy technology and climate change**

The Kyoto Protocol has committed OECD governments that are Parties to Annex 1 to take actions to reduce greenhouse gas emissions. Technology will play an important role in achieving targeted reductions in emissions and can facilitate reductions at lower cost. Important energy technologies include large-scale wind turbines, photovoltaics, nuclear power, natural-gas-fired combined cycle turbines, and fuel cells for transportation and power generation.

The adoption of these technologies has been slow. Long lead-times are needed for the refinement and commercialisation of new energy technologies. Investments in replacement stock with improved environmental performance are costly and only periodic for industry. Most energy technologies with superior environmental performance are more expensive than current techniques. Relatively low prices for fossil fuels make it difficult to justify replacing them from the cost perspective of an individual agent. Getting the prices right for energy inputs will help get the right technologies in place.

The technologies needed to meet the Kyoto targets are mostly available "on the shelf" today, but governments may need to take action to ensure that they are broadly implemented. Demonstration and diffusion programmes can help make clean energy technologies more widely known and available. Verification and certification programmes can help more experimental energy technologies clear the last technical and regulatory hurdles. Research and development partnerships with industry can accelerate the emergence of new energy technologies. Government procurement programmes can steer technology development towards a sustainable path. Fiscal and financial incentives may speed up the adoption of innovative energy techniques.

Beyond Kyoto, ever more demanding targets for reduced emissions will be required. Current, even cutting-edge, technologies may not be able to meet such targets. In the longer term, fundamental research on alternative energy technologies is needed to lower emissions. Changing practices of energy use and consumption will also help put the world on a lower-emissions path. Governments need to promote lifestyles and technologies that alter the relationship between the supply of energy services and environmental degradation. They need to work together to underwrite the research and development costs for technologies which are crucial for addressing global-scale ecological issues.

Source: OECD, 1999*a*.

III. SETTING FRAMEWORK CONDITIONS

Technological breakthroughs for sustainable development can be promoted by incorporating environmental and social criteria into innovation systems.

Enterprises are the motors of innovation and their performance depends on the incentives they receive from the economic and regulatory environment. For example, reforms may be needed in *intellectual property regimes* to stimulate innovation and technology diffusion; in *competition policies* to promote healthy rivalries and to facilitate collaborative research; in *education and training policies* to develop human capital on a continuing basis; in *financial and fiscal policies* to enhance the availability of capital to innovative firms; and in *communications policies* to increase the flow of information. Developing technology for sustainable development can be facilitated through an improved understanding of the innovation process.

New insights into the nature of the innovation process have changed perceptions about the appropriate role of governments (OECD, 1997). The specific instruments of science and technology policy are being adapted within a broader framework that stresses the importance of policy coherence and of interlinkages within innovation systems. Policies to promote research collaboration, facilitate firm networking and clustering, encourage institutional ties, diffuse technology and increase personnel mobility are taking on new significance. However, the success of these approaches depends on the overall policy environment, encompassing both macroeconomic and structural conditions. Policy coherence also implies improved integration of environmental and technology policies and better co-ordination among environmental and technology agencies. Some recent approaches to environmental innovation have been based on the concept of "*environmental clusters*" (Box 2).

One of the most important framework conditions for innovation to support sustainable development is technology pull from consumers and markets. It is often not a lack of research, but a lack of demand that limits technological progress as well as a lack of correct pricing. Industry will not have an incentive to produce greener products or to invest in cleaner production processes in the absence of market rewards. Making the leap to less wasteful consumption in the longer term will require changes in existing styles of working and living and from the highly resource-intensive habits that now predominate. Research indicates that awareness of environmental issues is on the increase among consumers, but this has not yet translated into far-reaching changes in everyday buying and living patterns. Although environmental investments are starting to be rewarded in the marketplace, public policies should seek to accelerate these trends and strengthen market pull.

Governments are taking initiatives to shift consumer behaviour towards modes that are more supportive of the environment. They can implement mandatory and voluntary product standards to promote energy and water efficiency. They can use taxes to influence consumption away from harmful goods, such as certain batteries or fuels, and encourage the development of substitutes. They can support eco-labelling schemes to inform consumers on the environmental characteristics of

Box 2. **Fostering environmental clusters**

Innovation mostly occurs within clusters of inter-related firms. Firms generally do not innovate alone. Rather they interact with similar companies, specialised suppliers, service providers, firms in related industries, and associated institutions such as universities and research institutes. Such clusters revolve around knowledge spillovers, pooled labour markets and exchanges of products and technology. As seen in Silicon Valley, they are usually found at the juncture of an entrepreneurial business climate, readily available risk capital and a business-friendly academic infrastructure. Clusters might also be based on geographic or natural resource advantages. Innovative clusters are emerging as drivers of growth and employment and are determining the pace and direction of development for entire regions, industries and sometimes countries. Governments can influence the development of clusters. Regional and local policies and development programmes can play a nurturing role. National governments must establish the appropriate frameworks in terms of competition, education, and financial and other policies. Newer approaches to stimulating cluster creation are also being tried by OECD governments, ranging from focused R&D schemes and competitions for funding to public procurement and investment incentives.

Finland launched an *Environmental Cluster Research Programme* in 1997 to promote both environmental entrepreneurship and sustainable development. It targets the emerging environmental goods and services industry, one of the country's fastest-growing sectors. The government provides seed funding for research on new environmental technologies to be carried out by consortia of producers and suppliers, universities and institutes. Collaborative projects enhance networking among researchers and users and facilitate innovation. Improving eco-efficiency through the application of life-cycle techniques in agriculture, forestry, basic metals and water management is the initial subject for research. The Ministry of the Environment co-ordinates the programme together with the Ministry of Trade and Industry, the Technology Development Centre (TEKES) and the Academy of Finland.

Source: OECD 1999*b*.

products and processes and broaden their choices. They can encourage reporting by enterprises on emissions and the environmental implications of their activities, as well as increase public access to these registries. They can use green government procurement and encourage green investment instruments to further sustainability priorities. Mostly, governments can overcome information deficiencies by increasing consumer knowledge of the ecological impacts of their behaviour and product choices and of the potential benefits of alternative consumption patterns. However, resolving many of the environmental challenges posed by current market trends, such as growing demand for more mobility and transport, may require more far-reaching changes in consumption behaviour. It will also depend on broader societal participation and support, as well as on government co-operation with industry, the media, schools and other influential institutions and groups.

Public resistance to certain technologies can also be a barrier to use. New technologies can lead to pressures on natural resources and health and safety hazards and raise difficult ethical considerations for society. There are major trust implications for technology acceptance, which may result in certain technology options being rejected or inadequately developed. For example, both nuclear energy and biotechnology may offer valuable technical solutions to enhance sustainable development (OECD, 1998*a*). A challenge is to increase our knowledge and public understanding of the social costs and benefits of alternative technologies, which involves agreeing on approaches for risk management. Public perceptions and understanding of different technologies can be enhanced by broader involvement of society in setting research agendas and standards of use and oversight. This will help stimulate technology development that responds to the broader needs and preferences of society.

IV. FORMULATING ENVIRONMENTAL POLICIES

Environmental innovation takes place mostly in industry, where environmental policies and regulations are an important influence. The need to comply with environmental regulations has led industry to develop and adopt various pollution-control techniques and equipment. However, traditional forms of environmental regulation have not generally led to radical technological change, although they have contributed to significant pollution abatement over the years. In many cases, command and control approaches have been a predictable stimulus to small, incremental improvements along established pathways, often in the form of end-of-pipe technologies. More dynamic environmental policies that promote prevention rather than abatement, and the development of clean technologies and integrated approaches – including economic instruments – are needed (OECD, 1999*c*).

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 entail disruptions and costs. *Performance standards* are technically flexible while *technology specifications* tend to stifle innovation. *Economic instruments*, such as pollution charges and tradeable 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.

In general, economic instruments should be used more frequently as substitutes for and complements to traditional forms of regulation. Changes in implementation as well as new approaches could also 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 help 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 meeting compliance. Also valuable are new types of voluntary agreements and approaches such as extended producer responsibility, disclosure requirements and environmental management systems, which can encourage changes in resource inputs and the complete redesign of products and processes.

V. DEVELOPING ENVIRONMENTAL TECHNOLOGIES

Shrinking research budgets and shorter research timeframes in industry and government raise concerns about the long-term innovation needed for sustainable development. Governments must assure a continuing basic research and development (R&D) effort on broad enabling technologies to support sustainable development goals. However, R&D related to the environment is only a small share of public research portfolios in OECD countries: about 2% of R&D budgets in the case of research directly on the environment, as narrowly defined, and an estimated 5% when environment-related research on other objectives is added, such as that on energy, agriculture and the atmosphere. It is true that research in many technology fields – such as biotechnology and information technology – can lead to beneficial environmental spillovers. In the case of information technology, new developments can help organisations monitor different aspects of their environmental performance at reduced cost. But overall, given the pressing nature of many ecological concerns, government expenditures on research that could be environmentally beneficial seem to be very low by most measures and may thus warrant review.

From the perspective of concepts such as *eco-efficiency* and *resource efficiency*, environmental technologies are those which minimise the resource and energy intensity of goods and services and polluting emissions (OECD, 1998*b*). They are technologies that enhance society's overall management of its resources. Technology foresight exercises have been one means of identifying useful technologies and important areas for research, including in the environmental realm (OECD, 1999*d*). Although not intended to pick "winners", technology foresight helps enterprises and countries to identify useful areas for research and development. And the foresight process is valuable in forging linkages between society and research and generating interactive processes to match technology development to social needs and market pull. Recent foresight studies have underscored the seriousness of ecological challenges and the importance of environment-related research. They have highlighted a number of key technologies for sustainable development, *e.g.* biotechnology, information technology and fuel cells, as well as specific applications, *e.g.* clean cars (Box 3).

Box 3. **Technologies for sustainable development**

Clean car technologies. Future cars could feature alternative batteries, lightweight materials, direct injection engines, fuel cells and/or enhanced recyclability – all leading to lower fuel consumption and emissions.

Photovoltaics. Buildings, automobiles and decentralised power units using photovoltaics or light-based energy are envisioned.

Biotechnology. Biotechnology holds vast potential for sustainable development. Bioprocesses can reduce resource inputs, pollutants and wastes from manufacturing. Agro-genetics can limit adverse impacts from pesticides and other chemicals in agriculture as well as enhance food security.

Advanced sensors. 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. Global information systems can aid precision farming, saving resources while maximising output.

New materials. Advanced materials technologies will facilitate recycling of consumer goods and of manufacturing inputs and further the implementation of life-cycle concepts.

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

Smart waste treatment. Approaches to reducing municipal waste, cleaning up hazardous waste and treating nuclear waste will be based on new enzymes, catalysts and other advanced techniques such as transmutation.

Renewable energy. Improved power storage technology and combined conversion systems will increase the use of electricity from renewable sources such as solar power, wind power and biomass.

Source: OECD, 1999*d*.

While new technologies are primarily developed and brought into use as a result of business decisions, governments also play a role in developing technology and are increasingly conducting applied research in partnership with industry. Such public/private partnerships are a means for doing more with less, although there may be risks of misdirecting resources and capture by private interests. They can leverage private investments in innovation and direct it towards critical research needs. They can enhance linkages among enterprises, and between enterprises, universities and public research institutions, and foster interactions that are crucial to the innovation process. In the environmental realm, partnerships are valuable because they reduce obstacles to the development and diffusion of clean technologies. Many OECD governments are initiating partnerships to develop technologies that can contribute to both sustainable development and industrial competitiveness (Box 4). Further evaluation is needed on the cost-effectiveness of such partnerships and on their influence on longer-term technology development and research-related linkages.

Box 4. **Examples of environmental technology partnerships**

Canada – Technology Partnerships Canada. Environmental technology is one of the three categories supported by this programme which provides repayable contributions for research on technologies for air pollution control; water and wastewater treatment; clean cars/transportation systems; climate change; and recycling.

Germany – Research for the Environment. A 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".

Japan – Research Institute of Innovative Technology for the Earth (RITE). RITE has created a partnership scheme to develop technologies for reducing greenhouse gas emissions, using biotechnology in production processes, developing substitutes to ozone-depleting substances, and monitoring techniques for air, water and soil pollution.

United Kingdom – Foresight Vehicle Programme. A LINK scheme aiming to develop a clean, efficient, lightweight, telematic, intelligent, lean vehicle which will satisfy stringent environmental requirements while meeting mass market expectations for safety, performance, cost and desirability.

United States – Industries of the Future Initiative. A collaborative effort between the Department of Energy and seven energy-intensive industries (steel, aluminium, metal-casting, glass, chemicals, petroleum refining and forest products) to develop competitive technologies which fully integrate energy and environmental considerations.

Source: OECD, 1999*c*.

As already mentioned, cleaner technology exists that is not yet in widespread use because of its price, the lack of information on the part of firms or the need to adapt it to users. Diffusion of technology and know-how is essential to enhancing participation in the sustainable development process. To this end, OECD governments are implementing schemes to disseminate information about clean technologies and to promote enhanced use of these techniques (Box 5), although such programmes must be carefully designed and evaluated to ensure cost-effectiveness and avoid unfair subsidisation. Encouraging information flows 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 that illustrate the technical feasibility and benefits of new

Box 5. **Examples of environmental technology diffusion schemes**

Australia – Cleaner Production Demonstration Project. This project aims to promote implementation of cleaner production technologies and processes through hands-on demonstration of innovative techniques.

France – Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME). A specialised agency which assists enterprises to reduce usage of energy and raw materials, to limit waste production and maximise recovery and re-use of waste, to reduce noise pollution and to prevent and/or treat soil pollution.

Ireland – Clean Technology Centre. An independent, non-profit corporation supported by a combination of public and private sources to advise and assist industry and public authorities on the adoption of waste minimisation techniques, clean technologies and cleaner production methods.

Netherlands – Cleaner Production Programme. A programme to disseminate information and stimulate the utilisation of clean technology in smaller firms, focusing on the food, wood and furniture, printing, chemicals, rubber and plastics, building materials, metal products and motor vehicle sectors.

Norway – GRIP Centre for Sustainable Production and Consumption. A GRIP (Green Management in Practice) centre to stimulate adoption of innovative environmental management practices in the public and private sectors, particularly smaller firms, through information dissemination and demonstration.

United Kingdom – Environmental Technology Best Practice Programme. A scheme focusing on waste minimisation and the use of cleaner technologies through the dissemination of "good practice" guides in the foundry, textiles, paper and board, volatile organic compounds, glass, food and drink, chemicals, printing, metals finishing, ceramics, and plastics and packaging industries.

Source: OECD, 1999*c*.

environmental technologies, and benchmarking schemes that help firms compare their environmental performance to that of similar enterprises. Technical assistance programmes provide more hands-on advice in diagnosing environmental problems and recommending responses. Governments are also mounting "soft" diffusion activities focusing on workforce training and encouraging managerial and organisational changes within firms to improve their ability to assess and adopt clean technologies.

Fiscal incentives may also be used to encourage the take-up of environmental technologies. The scope for diffusing technology is often limited by low capital stock turnover rates, averaging ten to 15 years for many manufacturing processes. Businesses generally bring new technologies into play only when the existing capital equipment is replaced. To speed up this cycle, some countries are giving accelerated depreciation allowances or investment tax credits targeted to environmental investments. For example, Finland offers accelerated depreciation for investments in air and water pollution control. Canada allows certain energy conservation and renewable energy equipment to be written off at a 30% declining rate. The Netherlands offers accelerated depreciation on expenditures that improve energy efficiency and for pollution-prevention equipment. Regional governments are also experimenting with environmental tax credits. For example, Quebec offers a 20% tax credit on investments in clean technology. In the United States, pollution-control technology gets tax relief in Illinois, recycling equipment investments are eligible for tax deductions in Virginia, and Oregon has tax credits directed at specific pollution-prevention technologies. However, such programmes are still too limited and recent to evaluate their effectiveness in stimulating such investments and in determining their optimal design so that they have real value-added benefits.

VI. ADDRESSING INTERNATIONAL ISSUES

Sustainable development depends on the application of clean technologies on a broad scale by non-OECD as well as OECD countries. A special challenge is to enable developing countries to take full advantage of energy-efficient and cleaner production options and to adapt them to their needs. The main constraints in many of these countries relate to a lack of human, institutional, technical, managerial and financial capacities needed to manage technological change. Support for the dissemination of technological know-how, therefore, must concentrate first on capacity development to underpin the long-term application of new technologies. Since the private sector is the largest source of finance for cleaner production and a major actor in technology innovation, diffusion and application, policy efforts should also focus on providing the private sector with an open, competitive and sound policy environment.

In this context, development co-operation can act as a catalyst to foster public and private actions at the policy, sectoral and firm levels. While developing countries must take a leadership role, donors can assist in vital areas like capacity building and the formulation of policy frameworks conducive to increasing demand for cleaner technologies. This includes designing market incentives such as removal of inappropriate subsidies and the introduction of user fees and fiscal incentives and ensuring the necessary institutional mechanisms for their implementation. Official Development Assistance (ODA) in these areas aims to complement and leverage investments in cleaner technologies which depend primarily on domestic resource mobilisation and access to foreign direct investment. Special schemes have also been set up to assist developing countries in addressing specific environmental concerns, including the Global Environmental Facility (GEF), the

Box 6. **Climate Technology Initiative**

Through the Climate Technology Initiative (CTI), countries are working together to support the objectives of the Framework Convention on Climate Change through joint science and technology programmes. The CTI provides a framework for countries to collaborate to accelerate the contribution of technology to addressing the problem of global climate change. The wider adoption of existing climate-friendly technologies and the development and deployment of new and innovative technologies are an important part of the climate response. The CTI was launched at the First Conference of the Parties (COP1) in Berlin, Germany in 1995 by 23 IEA/OECD countries and the European Commission. It has evolved to include regional workshops and country-specific consultations on the best climate-friendly technology options.

In addition to sharing the experience and benefits of national climate technology research and programmes, the CTI promotes and sponsors joint research and development on climate-friendly technologies. Four multilateral research projects were launched at COP3 to investigate ocean sequestration of carbon dioxide, geological sequestration of carbon dioxide from fossil fuels, combustion in recycled CO_2/O_2 mixtures, and very large-scale photovoltaic power generation systems utilising desert areas. Collaborative research proposals are also being developed on: hydrogen production from fossil fuels; biological hydrogen production; chemical CO_2 fixation and utilisation; different pathways for methanol production; transportation fuels from biomass; CO_2 as a chemicals industry feedstock; and integrated supply of heat and CO_2 to the horticultural industry.

Source: OECD, 1999*a*.

Multilateral Fund for the Implementation of the Montreal Protocol, the Clean Development Mechanism established under the Kyoto Protocol, and the UNIDO/UNEP National Cleaner Production Centres Programme.

Some problems are so global in nature that only concerted international action can resolve them. Addressing issues such as climate change, ozone layer depletion, desertification and biodiversity will require joint action by countries to develop and disseminate innovative technology. Large-scale and long-term, these issues require the insights of many disciplines and the efforts of many countries to be understood and addressed. Individual researchers and countries cannot solve these problems on their own. The world's most advanced science and technology resources are concentrated in the OECD countries and much more co-operation could occur in a wide variety of areas of research and development. Research co-operation and technical collaboration is crucial for attaining the most critical sustainable development goals, such as addressing climate change (Box 6).

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TECHNOLOGY, PRICES AND ENERGY EFFICIENCY

Table of contents

This article was written by Fatih Birol and Jan Horst Keppler of the Economic Analysis Division of the International Energy Agency (IEA).

I. INTRODUCTION

Energy efficiency determines the amount of energy needed to deliver valuable goods and services. In market economies, energy efficiency is determined by the state of the technology, the preferences of consumers, structural parameters such as climate, geography and culture, and the price of energy relative to other economically relevant inputs. Frequently, there exists a special interest in accelerating the rate of energy-efficiency improvements. To the extent that increases in technical efficiency lead to reduced energy use per unit of output, higher energy efficiency means lower imports, slower resource depletion, less environmental damage and lower costs per unit of output.

Energy efficiency is of particular importance in the context of the commitment of most Member countries of the International Energy Agency (IEA) under the Kyoto Protocol to reduce until 2012 their *absolute* annual greenhouse gas emissions by, on average, 6% below their emission levels in 1990. A large part of these emissions, around 70%, are energy-related. Since this commitment is coupled with the desire to maintain vigorous economic growth, it will only be achievable with massive decreases in energy intensity, the ratio between energy consumption and output. The crucial question in this context is whether such decreases in energy intensity can be brought about by improvements in the technological efficiency with which energy is used.[1]

This article analyses the different answers to this question, relying on basic economic theory and some empirical evidence. It also highlights the different implicit and explicit assumptions of various research communities which have led to vastly differing answers in the past. It proposes a conceptual framework in which to approach the question of the extent to which technology policy can accelerate efficiency increases in order to decrease energy intensity, or whether alternative policy instruments, primarily economic instruments which influence the relative price of energy, have to be used in addition.

II. TECHNOLOGICAL EFFICIENCY AND ENERGY INTENSITY

Improvements in energy efficiency are frequently, and wrongly, confused with decreases in the energy intensity of output. An improvement in energy efficiency, typically the introduction of a new technology, certainly *can* improve energy intensity. The latter, however, is also determined by other factors such as relative prices, cultural habits, geography, climate and state of development. The link between technological efficiency and energy intensity, of course, grows more tenuous the higher the level of aggregation, *i.e.* whether one considers the energy intensity of a plant, a sector, or a whole economy.

However, even at the level of the individual firm, energy efficiency improvements do not translate into one-to-one energy intensity improvements. In fact, technological energy efficiency improvements themselves can set in motion processes in which new factor combinations are employed, thus relativising the link between energy efficiency and energy intensity. This issue will be discussed in more detail below as the "rebound effect". An energy efficiency improvement in this context is understood as an improvement in the productivity of the factor energy. Strictly speaking, it refers to the improved productivity of capital, *i.e.* a machine which is specifically dedicated to the use or transformation of energy.[2]

A frequently cited measure in policy discussion is national energy intensity, *i.e.* the ratio between the total energy consumed in a given year and the gross domestic product (GDP). A typical relationship between economic growth, energy use and energy intensity might take the form 3:2:1, *i.e.* an economy which grows by 3% per year and in which energy use grows by 2% will experience an energy-intensity improvement of 1%. As mentioned above, energy intensity is an imperfect measure of energy efficiency, due to structural differences between countries. Even as a measure for comparisons over time for a single country, the value of the intuitively appealing ratio of energy use to GDP as an informative parameter for policy making has been questioned (IEA, 1997).

In fact, yearly figures of national energy intensity aggregate a multitude of different relationships between energy use and value creation and hide success stories as well as failures. An economy will typically contain some sectors in which energy use per unit of output has been decreasing rapidly and others in which progress has been slow or scant. Also, GDP growth varies over the business cycle, lowering and raising energy intensity, as energy consumption is less variable than overall output. Last but not least, there are variations in the degree to which fuel switching in different sectors is desirable. Home heating with brown coal or private car use creates environmental problems different from large-scale power generation, even if climate-relevant greenhouse gas emissions are a concern for both uses.

So, how much can one deduce from economy-wide figures of energy use? That very much depends on the perspective one has of the degree of interaction between different sectors. At this point, it is useful to introduce a distinction, which will be of concern also below – the distinction between engineers and economists.[3]

The nature of their respective disciplines tends to lead them to favour distinct approaches. Engineers stress the particular structural characteristics of a problem, whereas economists will emphasise underlying generalities and interdependencies. Of course, there is no absolute right or wrong, everything is at the same time unique and similar to something else.

In a market economy, individuals will strive to maximise their individual well-being without much regard for each other and yet their actions interact and are driven by the, ultimately, common results of their actions, such as market prices. Engineers emphasise the first part of the preceding sentence, economists the second.[4] The two quotes below exemplify the two approaches. Subsequently, the interaction between these two approaches and their success in achieving energy efficiency will be discussed.

– *Quote* 1. There are hundreds of millions of them: households and car drivers; millions of truckers; hundreds of thousands of building operators; farmers and factory managers. These are the people, the armies of discrete individuals, who make the decisions that govern energy use and CO_2 emissions. ... What they are interested in is producing goods, rendering services, heating houses, driving to work and hauling freight, to name just a few. ... Energy serves as a means to these ends. *The ends themselves define the proper study* of how and why people burn hydrocarbons and ultimately release carbon dioxide into the atmosphere [our italics]. (IEA, 1997, p. 11.)

– *Quote* 2. Fundamentally, in a system in which knowledge of the relevant facts is dispersed among many people, prices can act to co-ordinate the separate actions of different people.... Assume that somewhere in the world a new opportunity for the use of some raw material, say, tin, has arisen, or that one of the sources of supply of tin has been eliminated. *It does not matter for our purpose – and it is significant that it does not matter* – which of these two causes has made tin more scarce. All that the users of tin need to know is that some of the tin they used to consume is now more profitably employed elsewhere and that, in consequence, they must economise tin. ... If only some of them know directly of the new demand, and switch resources over to it, and if the people who are aware of the new gap thus created in turn fill it from still other sources, the effect will rapidly spread throughout the whole economic system and influence not only all the uses of tin but also those of its substitutes and the substitutes of these substitutes, the supply of all the things made of tin, and their substitutes, and so on; and all this without the great majority of those instrumental in bringing about these substitutions knowing anything at all about the original cause of these changes. The whole acts as *one* market ... [our italics]. (Hayek, 1945.)

III. DETERMINANTS OF ENERGY EFFICIENCY

Consumer preferences, the structure of the economy, the state of technology and, finally, the price of energy relative to other factors of production all determine the degree of technological energy efficiency, as well as energy intensity. Concerning the role of technology in determining energy intensity, one has to distinguish different *existing* technologies which can be used to produce a given output, all of which might not be used at a given point in time, from genuinely *new*, presumably more energy-efficient, technologies to produce the same output.

In competitive markets, the relative prices between energy, capital and labour will determine which available technology is selected. Higher energy prices will imply energy-saving technologies with high shares of capital and labour, and conversely, lower energy prices will imply technologies with a larger share of energy inputs and relatively lower shares of capital and labour. The actual changes will also depend on the substitutability of energy with other factors of production, as well as its absolute share in production.

In turn, this choice of technologies will determine the overall energy intensity of production of a plant, a sector or an economy. A good example of this working of the price mechanism with *existing* technologies is constituted by the choice of technology for power generation from coal. The question whether a critical plant with 38% efficiency or a supercritical plant with 45% efficiency will be constructed depends primarily on the price of coal. In the absence of regulatory constraints, the supercritical plant will only be built if the price of coal is high. From the point of view of a private decision maker, it is of secondary importance whether the price of coal is high due to the scarcity of the resource or due to an environmentally related price instrument, say a CO_2 tax.

Prices are thus one of the crucial variables to determine energy efficiency. And politicians have several instruments at their disposal to influence the relative price of energy. The most important among these are taxes on energy use or energy-intensive products, subsidies for alternative processes or products which consume less energy, and trading schemes in which large energy consumers can trade a limited amount of permits for the emission of energy-related pollutants. In the absence of any dynamic benefits (see below), changes in relative prices through taxes or subsidies lead to economic efficiency losses in private-good terms (*i.e.* those goods which are part of GDP accounts) and to lower growth, even if they create benefits in public-good terms (*e.g.* energy security, environmental impacts).

It is clear that with a given set of technologies, a one-time change in relative prices results only in a one-off increase in energy efficiency. The described mechanism thus concerns a static, or "lasting" framework in terms of main structural components and infrastructure. It will be discussed below how shocks to the economy and the energy sector can re-define the energy-output relationship.While imperfect, such an approach based on the idea of a "lasting" framework can nevertheless provide some insight, for instance by comparing price-energy intensity relationships over different countries at one point in time. Of course, such simple comparisons do not tell the whole story, as climatic differences, average distances travelled (depending on the size of the country) and other structural parameters also influence energy intensity. However, cross-country comparisons between energy intensity and retail gasoline prices show a highly inverse relationship between prices and energy intensity, which would be difficult to explain by structural factors alone (IEA, 1998).

Another possibility to induce the choice of the more energy-efficient among the existing technologies is to mandate their utilisation by law or to impose regulatory constraints on less energy-efficient technologies. This would allow apparent prices to stay the same, while raising energy efficiency. Of course, such a shift would also impose economic efficiency losses, because the true price of providing energy services is now increased by the shadow cost reflecting the intensity of the regulatory constraint. Economic theory maintains that these losses would be even higher than with price-based mechanisms (see, for instance, Barde, 1995). Such regulatory solutions would also be limited to a "controlled" dynamic towards technological change (see below), as the mandated technological changes in the absence of an explicit price signal would be confined to the foresight and the knowledge of the regulator.

The other main factor driving energy efficiency are *new* technological developments, *i.e.* improvements of existing processes, inventions or completely new forms of satisfying energy-related needs and wants. To function properly, such developments depend on a great number of factors such as the existing infrastructure, the degree of knowledge and education in the labour force and the degree of experience with similar or ancillary technologies. The number of such new inventions is also related to the size of the resources which governments and private companies explicitly dedicate to such efforts. In addition, the effectiveness of such support depends on the development of the appropriate national and international institutional structures to deliver it.

Economists are easily convinced that public resources should be dedicated to research and development (R&D), in particular concerning demonstration and deployment, as long as the corresponding objectives have a strong "public-good" characteristic. They have, however, not developed very sophisticated approaches to such new technologies. New technological developments are often considered as increases in an economy's production possibilities, essentially unrelated to other ongoing activities. Expressions such as "autonomous technical progress" or "autonomous increase in energy efficiency" bear witness to this hands-off attitude.[5]

The third approach to analyse energy-efficiency improvements combines the two approaches outlined above. It argues that changes in relative prices not only influence the static combination of factors, but that these changes will also lead to a re-direction of research efforts for new technologies. An increase in the price of energy would in this framework not only lead to the use of the more energy-efficient among the available technologies, but also to increased research efforts for *new* energy-efficient technologies. The relative price change would thus lead to a dynamic of "induced technological change". Such research efforts will naturally concentrate on the most expensive economic input. In other words, if energy would become a cheaper factor than capital or labour, the incentive would be to economise on the latter, with obvious consequences for energy intensity.

The underlying logic is as follows: if technological progress is related in some stochastic fashion to the amount of resources dedicated to research, then it is profitable to allocate those resources to the area in which progress would bring the relatively greatest benefit. The idea of induced technological change is a modern version of John R. Hicks' "induced innovation" hypothesis. In this context, he wrote: "... a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind – directed to economising the use of a factor which has become relatively [more] expensive" (Hicks, 1932).

In principle, it should be an empirical question whether energy efficiency is best increased through changes in relative prices or through public investment in energy R&D or the combination of both. Techniques exist to determine whether energy-efficiency improvements over time are more closely related to relative prices or to research funding. In practice, however, this question is almost impossible to answer due to the fact that government spending on energy research can itself be related to the price of energy. Some governments, indeed, react in a manner consistent with the outlined dynamic of induced technological change.

IV. ENERGY INTENSITY AND GDP GROWTH

In order to understand under which circumstance energy intensity can decrease faster than GDP grows, one has to understand under which circumstance improvements in technological energy efficiency can translate into energy-intensity decreases. Improvements in energy efficiency mean that a given unit of energy is used more productively. Before beginning the discussion of how energy efficiency, the productivity of the other production factors and the growth of the economy are interwoven, the following three issues which determine the relationships between different factors have to be clarified:

– If more of one factor of production, say energy, is added to a fixed quantity of another factor, say labour, then with each added unit the marginal productivity of energy will fall and the marginal productivity of labour will rise, as long as the two factors are substitutable. Thus, factor shares and marginal productivities are inversely related. This relationship is also known as the "law of decreasing returns".

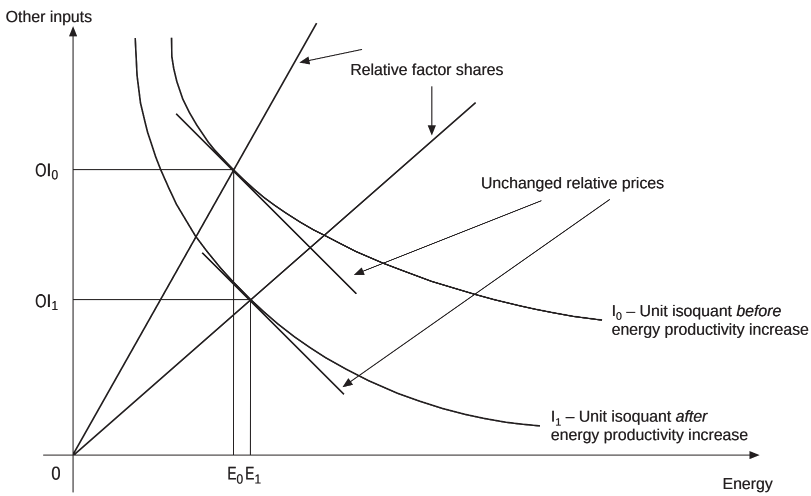
- As long as relative prices remain the same, the relative productivities of factors will in a competitive market always remain in the same relationship. If one factor becomes more productive but its price stays the same, then it is profitable to buy more of it. This will have the effect that due to decreasing returns its productivity will be lowered until it will eventually again correspond to its price. Thus, the ratio of the marginal productivities will always correspond to the ratio of relative prices. In other words, at the economic optimum (be it static or dynamic), economic inputs will be used in a manner such that the marginal value of output that a given amount of money, say one dollar, can buy is the same for all inputs.[6]
- What exactly constitutes an increase in the marginal productivity of energy? When talking about an increase in energy efficiency through technological progress, one usually refers to new, more energy-efficient *machinery*, *i.e.* capital or better management, through a better-educated workforce, *i.e.* labour. In order to avoid these problems, technological progress in the energy field has to be as exclusively dedicated to energy as possible. Otherwise, it is impossible to separate increases in the efficiency of energy from increases in the efficiency of capital and labour and from the overall growth rate of the economy. The example, which will be used in the rest of this discussion, is the following: a new refinery process doubles the calorific value of a tonne of fuel.

With these considerations in mind, one can proceed to the question of what happens to the share of energy in production, the energy intensity, when the marginal productivity of energy is increased. Since the price per tonne of fuel is assumed to remain the same, the price per *efficiency unit* will fall in proportion to the efficiency increase.[7] Thus, it is profitable to buy more efficiency units until the marginal productivity per efficiency unit will correspond to the new lower price. Other than by the size of the efficiency increase, this process is determined by the ease with which additional efficiency units of energy can be integrated into the production process; that is, the *elasticity of substitution*.

In the process of adding efficiency units, the marginal productivity of the other factors, capital and labour, will be increased since each unit of capital and labour is now working with more efficiency units of energy than before. In terms of efficiency units, not necessarily in terms of tonnes of fuel, *more* efficiency units are now employed per unit of output than before.

The process will continue up to the point where marginal productivities correspond again to factor prices. This is due to the fact that the relative price of energy in terms of efficiency units has been dramatically reduced, even if the price on a per unit of volume basis has remained unchanged. This implies that the other factors of production are reduced. Overall, less of each factor is now needed to produce one unit of output, which is equivalent to an increase in GDP growth. Figure 1 provides some illustration for this relationship; note that E_1, the new amount of energy in volume terms, can be smaller, larger or equal to E_0.

Figure 1. **Relative factor shares resulting from increased productivity of energy with unchanged prices**



This demonstrates the total "compound rebound effect". The rebound effect depends on the elasticity of substitution between factors, as well as on the elasticity of demand for the (now cheaper) final good. The higher the elasticity of substitution and the higher the elasticity of demand, the more the share of energy will increase after the improvement in energy efficiency. Its share will increase in the production of a specific good, as well as in the total economy, to the extent that goods using large amounts of energy in their production are now comparatively cheaper. Whether a technological improvement ultimately leads to increased or decreased energy use in volume terms depends on the elasticity of substitution. Normally, due to limited substitutability of factors, as well as of final goods, we would still expect some decrease in overall energy intensity, *i.e.* the rebound effect is a fraction between zero and one.

Thus, one cannot say *a priori* what impact a new energy technology will have on final energy intensity in the absence of any force which counteracts the fall in relative prices in terms of efficiency units. This is the heart of the rebound effect: a new technology which increases, say doubles, the efficiency of using an energy input automatically halves its relative price in terms of efficiency units.[8] This will have impacts on the proportional use of factors (substitution effect) and an impact on the total demand of the final product (output effect). If there is any substitutability at all, it can only be said that the increase in overall energy efficiency will be less than the increase in technical efficiency. To *lower* absolute energy consumption at unchanged prices while the economy is growing is therefore exceedingly difficult.[9]

In summary, at unchanged prices per unit of volume of energy, an efficiency-enhancing technological improvement contributes generally *less* to the reduction of energy intensity than the technical efficiency improvement suggests. This is due to three distinct effects:

- The real price decrease in energy services due to the increase in productivity, while the price of energy stays the same, will lead to an increased use of energy (in terms of efficiency units, not usually in terms of physical units) in production.
- Due to the fall in the real price of energy service (or energy-efficiency units), products which use energy will now become cheaper. The more energy-intensive a good, the more its relative price will fall. This leads to re-adjustments between economic sectors, with energy-intensive sectors gaining at the expense of less energy-intensive ones.
- An increase in energy efficiency is also a contribution to economic growth. The increased production will entail some fraction of additional energy to be used.

The fact that energy efficiency improvements contribute to economic growth due to the rebound effect (an important fact) has to be distinguished clearly from the additional energy use due to this incremental growth (a minor component of the overall rebound effect). In fact, economic growth consists of the introduction of new combinations of ever more efficient factors of production and the rebound effect *is* a growth-enhancing efficiency gain. There is thus a trade-off between the contribution of a technological improvement to decreasing energy intensity and its contribution to economic growth. The higher the elasticity of substitution between energy and other factors, the lower will be the impact on energy intensity and the higher the contribution to economic growth and *vice versa*.

V. ENERGY EFFICIENCY AND FACTOR SUBSTITUTION

These results have now to be qualified with respect to the following two questions. First, what happens if there exist no possibilities of factor substitution?

And, second, what happens if shocks prevent the normal working of the economic process? In the case that there exist no possibilities of substitution between energy and other factors of production, then the ratio between output and energy use is actually reduced in proportion to the increase in technical efficiency.

With zero substitutability, the technological improvement of doubling the per tonne efficiency of a fuel would indeed reduce by half the ratio between energy use and output. However, in this rare case the technological improvement will have *no* positive impact on output growth. In cases in which the other factors also experience efficiency increases, output would grow proportionately with the factor that experiences the smallest increase. Increasing energy efficiency beyond the ability of the economic system to fully absorb the increases will decrease energy intensity but will not make a contribution to growth.

Another question is what happens if prices on a per volume basis *do* actually change. A technological improvement in energy efficiency of the kind that has been described can be considered as an increase in the supply of the fuel, considered in terms of efficiency units. The increase in supply would lead to a fall in the price of efficiency units of fuel. The precise price change on a per tonne basis depends on the elasticity of demand for efficiency units of energy.

In the extreme case of no substitutability between factors, the demand for energy (on a per tonne basis) would fall if the fall in the price for efficiency units was larger than the proportional increase in efficiency. At the other extreme, prices would rise again if a very large rebound effect would lead to an increase in the demand for energy (on a per tonne basis). In between, there is very little that can be said about price changes on a per tonne basis, which as long as these two contrasting forces are at work will be of an order of magnitude smaller than increases in efficiency.

However, before engaging in a discussion of different assumptions concerning the crucial concept of substitutability, the limits of the reasoning so far should be briefly outlined. The relationships discussed are considered to be part of a stable economic framework. Now, it is conceivable that a major shock to this framework alters these relationships in a discontinuous manner. Three different kinds of these shocks are imaginable:

1. External shocks such as a war or major political shifts.
2. Major technological breakthroughs (such as the invention of electricity) as opposed to incremental improvements.[10]
3. Fundamental re-orientations of government policies and infrastructure provision (*e.g.* a large-scale commitment to nuclear power).

Such shocks upset the process outlined above, *i.e.* that a technological improvement will lead to an effective fall in relative prices, leading in turn to a new mix of factors and ultimately to increased economic growth.

In the case of such shocks, the normal structural adjustment of the economy to the new technical and economic opportunities is prevented for the following two reasons. The first one is that the sheer speed or magnitude of the technological development (this relates to the "breakthrough technologies" mentioned under point 2 above) happens too quickly to be fully translated into economic growth. The second one is that external factors, such as a war, or internal policy shifts supersede the market mechanism and hence prevent the usual adjustment. Thus, the external shock prevents the market mechanism from translating the energy-efficiency increase into economic growth for the time being. In other words, an external shock can, in fact, lead to decreases in energy efficiency through technological improvements as long as the economy grows more slowly than the technology advances. It should, however, be kept in mind that these efficiency improvements are acquired at a price in terms of potential output increases foregone. In the periods following such shocks, the economy catches up with a certain time lag, re-establishing the link between efficiency improvements and output growth discussed above. During these catch-up phases, the energy-intensity improvements of the economy are necessarily less than the trend.[11]

VI. THE ROLE OF TECHNOLOGY VS. PRICES

Apart from such major disruptions, the fundamental relationship that energy-technology improvements are equivalent to decreases in the relative price of energy (in terms of efficiency units) remains. The extent to which these energy-efficiency improvements are translated into increases in output or actual decreases in energy efficiency depends on the elasticity of substitution between factors.[12] If the substitutability between factors and final products is high, then technological improvements are subject to large rebound effects. If it is low, technological improvements lower the ratio of energy to output much more easily. The rest of this section is dedicated to exploring the assumptions under which the elasticities of substitution between factors and products are high or low.The discussion will focus on a number of facts that determine the elasticity of substitution and the manner in which economists and engineers (or their respective caricatures) tend to perceive these facts. Assumptions about the elasticity of substitution are frequently influenced by the practical and methodological constraints of each discipline. The first difference in perceptions concerns the *time frame* under consideration. Most people agree that the elasticity of substitution is very low in the short run, when the transition from one technology or one set of consumption goods to another is very costly.

The main difference between the two disciplines, however, relates to the importance given to the *long run*. In the long run, the technical possibilities of substitution are much higher. Different vintages of capital and labour have different lifetimes and are progressively substituted. In this process, new factor combinations are chosen according to new marginal productivities and prices. The biggest difference between engineers and economists in their approach to the possibilities of substitution lies in the distinction between *ex ante* and *ex post* substitution. For the economist, the world is an open field in which different factors of production and different consumption goods have to be combined in the most profitable fashion in response to their prices and marginal productivities. His view of the range of available choices concerning the technological structure as well as the structure of demand is *ex ante*.

For the engineer, instead, the world consists of a set of given technologies or activities, which determine demand in which relative shares are fixed. An increase in the productivity of one factor affects that factor alone. Prices cannot alter the technically (or psychologically) determined relationships or, if they can, then only in discontinuous jumps between existing technologies which he looks at from an *ex post* point of view. The distinction between continuous trade-offs between factors and sets of discrete technologies also determines the analytical tools in the two disciplines: differential calculus in economics and linear programming in the engineering sciences and operations research.[13]

However, the distinction between the engineer's and the economist's point of view concerns not only the dimension of time, but also the dimension of economic space or structure, as already highlighted in the discussion of the micro and macro views above. For the engineer, each discrete technology is there for its own reasons as expressed in Quote 1. For the economist, all technologies and, in fact, all possible products, are potential substitutes in the satisfaction of human wants and needs depending only on relative prices. All markets are interconnected, as expressed in Quote 2.

The different approaches are determined by the different guiding principles of engineers and economists, *i.e.* the technical feasibility of individual options or optimising behaviour in the light of a continuous range of options. They are brought into focus by the modelling approaches favoured by the two disciplines. In general, engineers favour so-called "bottom-up" models, in which the costs and the penetration potential of each technology is estimated without regard to substitution between factors or products and hence without regard for potential rebound effects. Step-shaped supply curves are built up by moving from the cheapest technology given externally imposed constraints to higher ones. Economists favour so-called "top-down" models which determine supply *and* demand on the basis of the same endowments and structural parameters and in which prices gear the optimal combination of factors.

Of course, it is easy for either side to point out the weaknesses ("lack of interactions", "lack of technological realism") in the approach favoured by the other side. There remains, however, one fundamental difference that is independent of questions of illustrative "realism" (which is also a function of available resources): traditional technology models did not include a demand side or other behavioural feedback among economic inputs and different parameters. In the case that demand was included, it was included as an exogenously formulated constraint and not as an endogenously determined variable. This implies that the essential property of an economic model, market clearing at equilibrium prices, is not fulfilled.

This disregard for the demand side (and its inherent possibilities for substitution between factors, goods, or even supplier countries according to prices) can lead in bottom-up studies to serious over-estimations of the market potential of different technologies. However, newer generations of models and increased co-operation between modellers from the two schools can combine the strengths of both approaches and eliminate some of the inherent conceptual limitations.

Concerning empirical results, the discussion will restrict itself to two historical examples which confirm the importance of prices. In an environment in which end-use prices have essentially been stable in real terms since 1982, the relationship between the growth rate in energy demand and GDP growth has remained by and large unchanged. On the other hand, the price impacts on oil consumption during the two oil shocks, when the relative prices of oil nearly doubled, have been considerable. While the oil intensity of IEA countries was steadily rising throughout the 1960s, it experienced a sharp turnaround in 1973 and has practically halved in the 20 years since the second oil shock. While the initial price hike led to severe economic disruptions, overall economic growth over the past 30 years has been sustained even while substantially reducing oil intensity.[14]

Energy *vs.* GDP trends increase in stability to the extent that the form of energy under consideration is more closely related to the ultimate service required from it, *i.e.* the greater the possibilities of substitution. Thus, the price of electricity has been less affected by the two oil shocks than the price of oil or its substitutes in power generation, coal and gas.[15] Consequently, the electricity trend prevalent in the 1960s has essentially been stable until today. Similarly, the relationship between mobility (measured as time spent in movement) and economic output is more stable than the relationship between output and fuel use, partly due to increased possibilities of substitution between the latter, partly also due to the dampening effect of the large tax component. This observation bears an important policy lesson: relative price changes are most effective where possibilities for substitution are highest.

VII. CONCLUSIONS

According to the preceding discussion, lowering the absolute consumption of energy in a growing economy only through technology improvements is close to impossible in a stable market economy unless corresponding price changes are introduced to keep the cost of the marginal efficiency unit of energy unchanged. Of course, it is always conceivable that technological progress delivers forms of energy that have no external side-effects, whether environmental or otherwise, and which would make the achievement of energy efficiency no longer a target for policy interventions. However, for the time being, such prospects remain speculations rather than options.[16]

If the objective of lowering absolute consumption of energy in a growing economy is taken seriously, relative price changes have to be taken into account.[17] If societies accept to employ relative prices to help achieve reductions in the energy-output ratio, this means that markets have to be enabled to fulfil their function of equating marginal costs and benefits. There exist many obstacles, particularly in the energy sector, hampering the efficient functioning of markets: subsidies which have lost all relation to verifiable public goods, high transaction costs and incentive failures make it difficult for decision makers to reflect the true costs and benefits of energy in their actions. Markets are complex institutions which need careful nurturing, prudent care and time to develop. The role of governments in this area is to remove disincentives such as obsolete subsidies, ensure that prices reflect the full costs of production, and lower transaction costs by providing information, establishing responsibilities and ensuring contracts.

Even with well-functioning markets, however, relative price changes alone will impose efficiency losses on the economy and lower economic growth. This is why energy-technology improvements are constantly required to keep the economy growing as the real price of energy gradually rises. Two conditions are thus necessary to bring about this state of affairs:

– Competitive markets have to be enabled by appropriate framework-setting policies in order to allow price transparency, quick reactions to changing structural conditions and the rapid diffusion of new technologies.
– Government policies to stimulate energy-technology improvements need to be strengthened. Efforts need to be concentrated in those areas which are least likely to crowd out private efforts and most likely to maximise positive spillovers. This would suggest, at first sight, areas such as basic research, co-ordination and technology diffusion.

While technological improvements alone will most likely not be able to reduce absolute energy consumption in a growing economy, they are a source of overall productivity improvements and economic growth. Everybody – engineers, economists, policy makers and ordinary citizens – agrees that achieving energy efficiency is a worthwhile goal. At the same time, as energy consumers, these very same people continue to demand more and more energy-related services or energy-intensive goods at effectively lower prices. This takes place while – or rather because – engineers and technicians are accomplishing admirable feats of technological progress.

An energy-efficiency improvement contributes to total factor productivity and to economic growth and is thus subject to potentially large rebound effects. Neither engineers nor economists alone will be able to deliver the twin objectives of reducing energy consumption and ensuring economic growth. Multiple objectives require multiple instruments. Only by combining the expertise of all the actors can the energy-efficiency conundrum be solved.

Coming to terms with the development of energy use in a growing economy requires taking into account the realities of the relationship between factor productivity, output growth and factor substitution. The near-impossibility of reducing energy use in a growing economy beyond its autonomous rate of growth at unchanged prices, requires that price-based instruments be included in the policy mix, both to induce more energy-efficient choices with existing technologies and to induce new technological developments.

As is the case for technological developments, price changes will most likely not be able to reduce the level of energy consumption in a growing economy. Price-induced increases in technological and economic progress will only be realised by the actions of engineers, technicians and managers. The ability of the price system to do its work depends critically on the flexibility and the inventiveness of the individual actors who together determine the level of output and energy use. For truly significant results, price signals and efforts to increase the capacity for technological improvements have to complement each other.

NOTES

1. In fact, to fulfil the Kyoto commitment, energy intensity would have to decrease *faster* than the economy grows. Another formulation of the question is thus, whether it is possible to fulfil the commitments under the Kyoto Protocol without explicitly changing relative energy prices (*e.g.* through taxes or permit trading) or by raising the share of renewable or nuclear energy in electricity supply through massive regulation.
2. Technically speaking, *energy intensity* refers to the share of energy in total production Q/E, an average value. E*nergy efficiency* refers to the marginal productivity with which energy is used *Q/*E. The relationship between the two values is not straightforward, but depends on the conditions under which energy is used.
3. Individual readers considering themselves to belong to one of the two groups should not be too concerned whether they recognise themselves in the characterisations. These characterisations are, evidently, caricatures chosen for expositional purposes.
4. The best-known expression of the economists' conviction that many different actions with unrelated intents and purposes will bring forward one, common, equilibrium outcome is the picture of the "invisible hand".
5. Both expressions have led to numerous misunderstandings in the past. In fact, they are nothing else but creative names for the unexplained residuals when accounting for the different influences which shape the ratio of energy to output over time. Strictly speaking, they have no explanatory value.
6. If there are two factors energy (E) and capital (K), and MP denotes the marginal productivity, then it holds that MPE/MPK = PE/PK. This implies that MPE/PE = MPK/PK = constant.
7. The distinction between energy units (constant physical quantity) and efficiency units (variable units needed to produce a given amount of output *ceteris paribus*) can also be formulated in terms of energy and energy services. The important thing to understand is, however, that an energy efficiency improvement *changes* the link between the physical quantity and the final value.
8. This does not mean that the final equilibrium price is half the original price, as the increasingly demanded quantities might only be forthcoming at rising supply prices. This, however, does not change the basic logic of the argument.
9. This would require annual technical efficiency increases of the magnitude g/(1 – rb), where g is annual GDP growth and rb is the size of the rebound effect. In the absence of relative price changes, which would lower the rebound effect, the most promising strategy to lower energy intensity would be to increase the productivity of factors other than energy, such as capital and labour. This effect, in fact, is behind the inverse link between energy intensity and *per capita* income.

10. Of course, in this context active technology policies also play an important role. However, it should be added that such breakthrough technologies are rarely foreseeable in advance and remain subject to great uncertainties and time lags between conception and implementation.
11. See also Starr and Searl (1985). The authors distinguish three major shifts in the relationship between US output and electricity demand in the last hundred years.
12. As mentioned above, the output effect and the size of the total rebound effect also depend on the elasticity of demand for the final product, whose price will fall even if no substitution between factors takes place. This impact will not be further explored in order to simplify the discussion.
13. These two approaches to the fungibility of factors are sometimes identified as characterising factors of production either as "putty" (economists) or "clay" (engineers). See also Richard *et al.* (1978).
14. For a more detailed discussion, see "Oil Price Changes and the Macroeconomy", EAD Working Paper No. 2, January 1999, p. 11.
15. This issue has been comprehensively analysed by the IEA before re-designing the new World Energy Model (WEM). On the basis of several econometric tests, including standard regression analysis and Granger causality tests, it was decided to model electricity demand separately. This is different from the previous WEM, where fossil fuel and electricity demand was modelled jointly, implying an expectation of price-induced interfuel substitution. For an in-depth technical discussion of this issue see "New Modelling Framework of EAD: Review and Suggestions", EAD Working Paper No. 1, April 1997, pp. 3-5.
16. The case of nuclear energy was and still is considered an option in this context, under the conditions that it would be acceptable to public opinion at commercially viable levels of safety and that solutions for long-term storage of waste were found.
17. Certain instruments are, of course, better applicable to some sectors than to others. Private energy users, for whom energy is often only a limited share of their budget, react differently to price changes than companies, which monitor their energy expenses carefully.

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STIMULATING ENVIRONMENTAL INNOVATION

Table of contents

This article was written by Yukiko Fukasaku of the OECD's Directorate for Science, Technology and Industry.

I. INTRODUCTION

Sustainable development implies changes in production systems in such a way that opportunities for future generations will not be sacrificed and that the quality of our lives will continue to improve. It is clear that economic growth is a pre-requirement for any changes to production systems. It used to be taken for granted that economic growth entailed parallel growth in resource consumption, and to a certain extent, environmental degradation. However, the experience of the last three decades indicates that economic growth and resource consumption and environmental degradation can be decoupled to a considerable extent. The path towards sustainable development entails accelerating this decoupling process. This can be done by changing the nature of economic growth, *i.e.* transforming what we produce and how we produce it.

Where this requires a radical transformation of products and production systems, innovation has a crucial role to play in putting our socio-economic system on the path towards sustainable development. In reality, it has only recently been generally recognised that technological innovation plays such a central role. In the past, technology was considered to be the source of the evil that destroyed the environment, rather than improving it. However, through the introduction of environmental regulations during the 1970s, it became clear that some environmental pollution, such as atmospheric pollution, could be abated by the introduction of technological innovations, *e.g.* desulphurisation equipment. Technology is now seen to play a positive role in contributing to environmental sustainability.

On the other hand, it can be argued that pollution-control technologies incur high development and operation costs for industry and tend to stifle economic growth and competitiveness. Environmental considerations and investments by industrial firms were seen as going against the objective of profit maximisation (and hence efficiency optimisation of the economy as a whole) and as detrimental to industrial competitiveness. This view tended to "lock in" the role of environmental innovations and regulations as "necessary evils" from the economic viewpoint and gave rise to a general perception that environmental regulation alone could halt environmental degradation. This, in turn, tended to make the environment an area of little interest for innovation and technology policy.

This position is increasingly being challenged. Environmental regulation can increase industrial competitiveness and make a positive contribution to economic growth by stimulating innovations that not only meet regulatory requirements but also enhance production efficiency and product performance. This view highlights the role of innovation and technology in realising environmental sustainability at the same time as enhancing industrial competitiveness. Recent trends in the interface between environment and innovation support the key role of innovation and technology in bringing about environmental sustainability. The first is the evolution of regulatory regimes away from command and control, technology specification and performance standards to integrate more economic instruments, which are a more potent policy tool for providing incentives for environmental innovation. The second is the parallel trend by industry to integrate improvements in environmental performance into their corporate strategy. This involves a shift in the corporate innovative response away from end-of-pipe solutions to the integration of cleaner and more resource-efficient processes and products.

II. ENVIRONMENTAL REGULATION AND COMPETITIVENESS

The effect of environmental regulations on competitiveness is a much debated subject. Conventional economic thinking predicts that compliance with environmental regulations incurs costs, undermining competitiveness and stifling economic growth. Environmental amelioration has been achieved, but at a cost to the OECD Member countries of 1-2% of their GDP (OECD, 1997*a*). In the ongoing debate, the definitions of costs and competitiveness are not always unambiguous and usually involve different dimensions. Jaffe *et al.* (1995) reviewed empirical studies looking at the effects of environmental regulations on international competitiveness in terms of changes in net exports of US industries (Kalt, 1988; Grossman and Krueger, 1993; Tobey, 1990), overall trade flows (Low and Yeats, 1992) and plant location decisions (Bartick, 1988; Levinson, 1992), and concluded that the adverse effects of regulation were small or statistically insignificant.

This study also reviewed empirical studies on the effects of environmental regulations on the productivity of the US industrial sector (Barbera and McConnel, 1990; Denison, 1979; Gallop and Roberts, 1983; Gray, 1987) and concluded that there were "modest adverse impacts of environmental regulation". This conclusion coincides with another study which concluded that "in the past studies have identified few impacts of environmental policies on competitiveness and international investment at the macroeconomic level" (OECD, 1993).

As pointed out in Jaffe *et al.* (1995), these analyses assume that regulations increase production costs, reducing productivity and investments and leading to negative economic growth effects. However, there has emerged another line of argument that contends that, on the contrary, regulations in fact reduce production costs and can stimulate growth and competitiveness. This argument has been advanced mainly by Porter and van der Linde (Porter, 1991; Porter and van der Linde, 1995), and has come to be known as the "Porter hypothesis". In its original conceptualisation, the link was mainly between strict national environmental regulations and the international competitiveness of the regulated industries compared to those in countries under less strict regulations (Porter, 1990, 1991), but the later formulations imply competitiveness also at the firm level.

Porter and van der Linde argue that the environment-competitiveness debate involving a trade-off between social benefits and private (industry) costs has been "framed incorrectly". In their view, the negative relationship between regulation and competitiveness stems from a static view of regulation and technology. The reality is that regulation and technology change constantly and industrial competitiveness depends on "the capacity for innovation and improvement". They further argue that "properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them". Such "innovation offsets" can even lead to absolute advantages over firms in foreign countries that are not subject to similar regulations.

According to Porter and van der Linde, the mechanism that links environmental regulation and industrial competitiveness is roughly as follows. Environmental regulations signal companies about resource inefficiencies in the processes they use and the products they produce; also, they point to potential technological improvements to overcome these resource inefficiencies. The signal generates a learning process in firms which leads to technological improvements to meet regulations. These "innovation offsets" have other resource efficiency enhancing effects (product quality improvement, energy efficiency enhancement, reduced wastes, etc.), and as a result their competitiveness is enhanced. The authors stress that this competitiveness-enhancing process spurred by environmental regulations is a dynamic one in which firms initially make sub-optimal choices, after which time successful firms dynamically change their innovative response and continue to improve their competitive position. Numerous examples of such "innovation offsets" are cited.

This and similar approaches to analysing the regulation/competitiveness relationship (*e.g.* Barbera and McConnel, 1990; Meyer, 1992) have been criticised by Jaffe *et al.* on the grounds that the approach "remains one with a high ration of speculation and anecdote to systematic evidence". Porter and van der Linde, on the other hand, stress the constant failure of an economics approach to find convincing evidence of the negative effects of environmental regulations on competitiveness and economic growth. In any case, as Jaffe *et al.* point out, it seems that "systematic empirical analysis of the Porter hypothesis is only beginning", and it is for future research to provide further and more systematic evidence.

The positive view of the regulation/competitiveness relationship does not say that environmental regulations do not incur costs. They do, but this view asserts that the dynamic innovative response that regulations generate, in the long run, raises the efficiency of a firm's production to the extent that the cost is offset by the competitiveness that such innovations bestow on the firm. This is closely related to the innovation economics view which attaches importance to the role of innovation in economic growth. Some studies indicate evidence that environmental regulations do spur innovative activities. A study correlating the relationship between environmental expenditures, on one hand, and patenting in environmental technologies, on the other, has found that in the United States, Germany and Japan, environmental expenditures (in response to environmental regulations or compliance costs) have spurred increased patenting in environmental technologies (Lanjouw and Mody, 1996). Another study has found that increases in compliance expenditures within an industry in the United States are followed by associated increases in R&D (Jaffe and Palmer, 1996). However, the question of whether regulation-inspired R&D leads to lower costs of production or new and improved products in the future remains unanswered. The study also points to the difficulty of establishing a causal relationship because of the unavailability of disaggregated data, and suggests that focused industry studies could overcome this obstacle and contribute to a better understanding of the regulation-innovation interface.

III. INNOVATION AND COMPETITIVENESS

The positive association between regulatory pressures, on the one hand, and industrial R&D investments and patenting activities, on the other, imply that innovation constitutes an important part of the industrial response to regulations. This qualification makes the environmental regulation and competitiveness issue basically a sub-set of a more general innovation and competitiveness issue. Here, innovation economics over the past few decades has argued for the positive role of innovation in enhancing competitiveness.

One thing that needs to be stressed and which has been made clear in innovation studies, is that any innovation incurs cost, and sometimes this can be high. This is the major counter argument to the Porter hypothesis that comes not only from economists but also from other management researchers. Walley and Whitehead (1994) criticise the easy "win-win" rhetoric of the Porter hypothesis by pointing to the fact that regulatory compliance is costly, especially in the traditional "dirty" industries such as petroleum, chemicals, and pulp and paper. In making this point, they do not revert to defending the adversarial corporate attitude to environmental regulations. They argue that the real issue for corporate management strategy is in enhancing the efficiency and effectiveness of corporate environmental spending, rather than searching for win-win solutions, which they argue are rare. For companies, the choice is between environmental benefit and *shareholder value*, rather than against regulatory compliance costs. In order to design sound corporate environmental strategy, a firm needs to know its environmental spending and resultant benefits, *i.e.* environmental accounting, to design an approach that ensures maximum environmental benefit at minimum cost which, in turn, would require a systematic, integrated and flexible approach.

Whether optimistic or pessimistic about the ease and benefits of promoting corporate environmentalism, both views clearly give innovation a central role in improving the environmental performance of industries. Whether a net cost is involved or not, it is through the innovative response that corporate environmental performance can be improved and, using appropriate corporate strategies, this can be done in such a way that corporate value is preserved or enhanced, leading in some cases to strengthened competitiveness. It may be noted here that some scholars in innovation studies uphold the view that the pursuit of environmental sustainability could become a pervasive trend that involves a deflection in the existing technological trajectory. Hence, in the long run, environmental innovations could play the central role in a new upswing of a long wave of economic growth in the manner that information technology and biotechnology are at the core of the present upswing (Freeman and Soete, 1997).

IV. THE CORPORATE ROLE

Whether corporate environmentalism leads to gaining an easy competitive edge or implies subtle trade-offs between environmental performance and corporate value, scholars (Howes *et al.*, 1997; Fischer and Schot, 1993) have observed that corporate environmental strategy has definitely changed from a defensive, reactive attitude to a proactive and positive approach over the last three decades. This change in business attitude took place in the mid-1980s. The phase prior to this was characterised by "resistant adaptation" (Fischer and Schot, 1993) of industrial firms which were generally reluctant to internalise environmental issues.

Firms did little more than comply in a minimal fashion to environmental regulations, and often fought against tighter regulations. During the 1980s, this reactive corporate attitude shifted to a more proactive and positive attitude to enhancing environmental performance. With regulation becoming based less on the adoption of specific technologies and more on ultimate environmental performance, firms could formulate their own strategies to meet such standards. Environmental issues have now become part of corporate strategies and firms can manage environmental issues in a more proactive manner. Most larger companies have adopted formal environmental policy statements, corporate environmental strategies and environmental management systems. Environment has begun to be internalised in corporate culture.

The transformation in corporate attitude to the environment is manifest in the "Declaration of the Business Council for Sustainable Development" contained in the aptly titled book, *Changing Course* (Schmidheiny, 1992), prepared to express the position of the Business Council for Sustainable Development at the Rio Earth Summit. The Declaration makes a clear commitment of the business sector to sustainable development, with an understanding that economic growth is basic to achieving it and that new technologies are needed to permit growth while enhancing resource efficiency. It declares that "progress toward sustainable development makes good business sense because it can create competitive advantages and new opportunities" but that at the same time it requires "far-reaching shifts in corporate attitudes and new ways of doing business". Furthermore, the Declaration calls for "new forms of co-operation between government, business and society" to reform markets, and calls for the promotion of eco-efficiency through pollution prevention, use of cleaner technologies and business partnerships to diffuse appropriate technologies.

This change in corporate attitude coincides with a parallel shift in industrial innovative response from the predominance of end-of-pipe technologies to cleaner processes and products. Shifts to cleaner processes and products are synonymous with pollution prevention, pollution source reduction, or process changes as they are sometimes termed. Cleaner technologies can generate environmental benefits and are often cost-saving from the corporate viewpoint. This shift is probably behind the rise of the win-win or double-dividend argument based on the positive correlation between environmental benefits and enhancement of competitiveness. Some studies give some statistical evidence of the shift to cleaner technologies. Lanjouw and Mody (1996) show the distribution of pollution abatement expenditure in the fields of air and water in the US manufacturing sector which indicate a growing share of "change in process" and decreasing share of "end-of-pipe" throughout the 1980s.

Although cleaner technology is attractive in concept, Howes *et al.* (1997) cautiously point out that in reality few companies use it consciously as a practical principle or tool to make corporate decisions. Cleaner technology is an abstract concept which means different things in different contexts. It includes a range of innovations, ranging from simple compliance investments and incremental cost-saving investments to more fundamental process and product innovations. Few companies consciously use the concept of clean technology to shape their strategies or their investment decisions, but rather they aspire to more efficient process technologies, which once adopted generally confer environmental benefits. In the long run, this could lead to reduced compliance investments and give a company more control over the environmental agenda. Cleaner technology is not a criterion for practical technology choice, but rather an element of broader corporate strategy which can refocus it at a higher level "in such a way as to build environmental criteria into decision making and the technology development process".

It is likely that the environment does not provide priority grounds for adopting cleaner technologies, but rather it is the cost savings associated with improved resource efficiency that provide the major motivation. This can be seen in the Japanese industrial response to the oil shocks of the 1970s, where the petroleum price increase in the overwhelmingly petroleum-dependent Japanese economy provided a powerful incentive for energy conservation efforts in the dirty mature sectors. The result was not only enhanced energy efficiency, but also enormously improved environmental performance and perhaps increased international competitiveness in many of these sectors in the 1980s (Fukasaku, 1995).

The shifting corporate environmental response over the last three decades and the resulting shift in innovative response from more end-of-pipe to cleaner solutions, reflect the increasing diversity that corporate management faces in making decisions to increase efficiency of corporate operations. Environmental regulations with their greater flexibility present *opportunities* rather than constraints for innovation and increasing competitiveness. Increasing diversity implies that it is a complex and difficult task to make appropriate decisions to optimise the efficiency of corporate operations. It is argued that such a diverse and complex set of opportunities "creates a managerial incentive structure that pervades all dimensions".

Galarotti (1995) enumerates the many dimensions of this incentive structure, from supply-side management, demand-side considerations, interdependencies in production and distribution to financial incentives. Supply-side management points to the need to take an integrated approach in enhancing eco-efficiency through implementing technological and organisational innovations, including inter-firm networking and co-operation. Demand considerations point to exploiting market opportunities presented by the growing demand for differentiated environmental products, and the need to meet requirements of the "green" supply chain through green procurement. Increasingly, "green" investors oblige firms to improve their environmental performance in order to add value to their stocks and improve access to credit. Thus the "greener" environment surrounding corporate operations is deliberately creating complex, but rewarding, opportunities and incentives to change corporate strategy.

V. INNOVATION AND ECONOMIC INSTRUMENTS

As corporate response to environmental issues has evolved over the last three decades, so has public policy in environmental regulation. The change here is generally characterised by a shift from regulatory regimes based on simple command-and-control type regulation or those based on technology specification to those that make greater use of market-based instruments. The change has been in the direction of putting in place a better incentive structure for improving environmental performance in the industrial sector, and integrating more flexibility in complying with regulations.

It is interesting to note that both the environmental economics approach and the business management approach argue that regulations are not equal in the effects they have. Jaffe *et al.* (1995) point out that environmental regulations are not equal in terms of their costs or their benefits. The so-called market-based or economic-incentive regulations, such as those based on tradeable permits or pollution charges, will tend to be more cost-effective than command-and-control type regulations. Hahn and Stavins (1992) assert that economic instruments are cheaper than imposing fixed technological or performance standards. This is because under a market-based regulatory regime, firms are likely to abate up to the point they find it profitable, with the firms that find it cheapest to reduce their levels of pollution cleaning up the most. They provide ongoing incentives for firms to adopt new and better technologies and processes because under these systems, it always pays to clean up more if a sufficiently cheap way of doing so can be identified and adopted.

Porter and van der Linde (1995) contend that regulations need to be "properly crafted" to generate innovative responses and to enhance competitiveness. Such "properly crafted" regulations would be based on creating the maximum opportunity for innovation in which the industry – not the regulator – can choose the approach. Also, regulations should be designed to stimulate continuous improvement, rather than locking in any particular technology. In concrete terms, such regulations point to economic instruments such as pollution taxes, deposit refund schemes and tradeable permits. A study examining the innovation effects of various environmental policy tools, concludes that some tools can stifle innovation and in general they differ in the kinds of innovation induced (OECD, 1999*a*).

Howes *et al.* (1997) summarise the advantages of economic instruments over standards as follows. First, in the short term, they can provide a given level of environmental improvement at a lower cost to society than is achievable through the introduction of standards, by allowing industry the flexibility to use the technology they judge to be most efficient and appropriate for their circumstances. Second, in the long run, they can provide incentives for continual improvements beyond those demanded by fixed standards. This could encourage innovation by encouraging polluters to change to cleaner technologies, and to develop new technologies since it pays to clean up more.

The introduction of market instruments results from the realisation of the inadequacy of more traditional regulatory approaches, mainly the command-and-control type approach based on technology specification. The main benefits of economic instruments are their potential for stimulating more *cost-saving* approaches by allowing *flexibility* in the innovative response and the ability to *create incentives* for continued innovation to enhance eco-efficiency. Also, with some instruments such as charges and taxes, revenues can be raised that can be channelled for other policy purposes. This approach clearly attaches central importance to the dynamics of industrial innovation in promoting environmental sustainability.

Economic instruments have been applied in a number of contexts in OECD Member countries over the past few decades. Examples are water effluent charging in the Netherlands, Germany and France, the NO_x charge in Sweden, and the water effluent and sulphur emissions trading in the United States. However, despite their obvious theoretical advantages, evidence concerning their performance and effects is limited, especially about their effects on technological change. One clear problem is the lack of data; however, a further major difficulty in evaluating economic instruments is that they are not applied independently, but often used as complements to more traditional regulatory regimes. Hence, there is difficulty in separating out their effects (OECD, 1997*b*).

Also, in real experience, their innovation effects seem to have remained mild because they were not set at high levels or used extensively (OECD, 1999*a*). Howes *et al.* (1997) point out that, in Europe, successful application of market instruments has been limited to the Nordic countries. In other cases, the introduction of regulatory regimes based on market instruments has been impeded by opposition from industries or disagreement about appropriate levels of taxes or charges, for example in the case of the failure to institute an EU-wide carbon/energy tax and a system of tradeable sulphur quotas.

The real-life difficulty of instituting a regulatory regime based on market instruments illustrates the bottlenecks in the path towards sustainable development. Theoretically effective instruments clearly face conflicts in arriving at an acceptable design in practice. Howes *et al.* (1997) observe that the process of negotiating a market-based instrument can be as tortuous as negotiating a traditional regulatory instrument, since a greater number of actors are involved and often the industry is nervous about ceding more revenue-raising powers to government through taxation. Tradeable permits can set companies against each other, whereas with traditional regulation companies have a common cause against government. Although there is considerable consensus that market-based instruments, in principle, offer a constructive way forward, they raise problems of equity and new procedural problems concerning their negotiation.

VI. INNOVATION FOR SPECIFIC ENVIRONMENTAL PROBLEMS

The foregoing discussion focused on the changes in the policy and corporate responses to environmental problems over the last three decades. What also changed during this period is the kind of environmental issues that came on the policy agenda, which in effect reflects the change in our perception of environmental problems. The change involves several dimensions. First is the shift in focus from local pollution problems to regional and global environmental problems. The change implied a shift away from problems with relatively straightforward solutions, such as reducing atmospheric emissions to improve local air quality, towards more unfamiliar, complex and diffuse issues, such as climate change.

The environmental issues that are now receiving increased policy attention are relatively less associated with production processes and more with consumption and post-consumption (Howes *et al.*, 1997). Dealing with climate change is as much a problem for consumers as for producers, as are such problems as waste reduction or more sustainable transport technology and systems. This shift in policy focus has developed in tandem with a growing perception that managing the flow of materials through the economic system – closing the materials loop – is the key to making society more sustainable. This trend is reflected in the penetration of notions such as resource or eco-efficiency and zero emissions. This, in turn, reflects a trend to identify common technological issues underlying environmental problems, whether global, regional or local, and focuses attention on feasible technological solutions.

This change in the perception of the environmental challenge clearly focuses policy and corporate response on innovation and technology. Issues such as waste reduction call for innovative *organisational* solutions. *Systemic* innovation is indispensable in devising sustainable transport systems. New, creative approaches to managing the material flow in production will require an *interdisciplinary* approach in searching for solutions. Even if the underlying problems are common and technical in nature, the approach to global-scale environmental issues such as climate change will require *international co-operation*.

The corporate response to environmental issues has evolved considerably over the past three decades. The reactive, adversarial attitude to environmental regulations and reluctant compliance through end-of-pipe solutions has given way to more proactive internalisation of environmental considerations in corporate operations through the adoption of strategies based on cleaner approaches to industrial production. In many companies, environment units have been established, corporate environmental statements drafted and internal environmental management systems developed. Some large firms are advancing in this direction and are ambitious enough to aspire to the title of "sustainable enterprise".

However, this evolution to a proactive corporate response has been neither simple nor straightforward. The introduction of new or more stringent regulations still tends to be met with resistance. The acceptance of the notion of the positive correlation between compliance with strict regulations and enhanced industrial competitiveness – the win-win or double-dividend argument – has gained ground, but not much ground. In general, larger corporations have been more responsive in developing positive environmental strategies while many small and medium-sized enterprises (SMEs) have experienced difficulty in moving beyond minimum compliance. Even many larger corporations have been slow to develop positive strategies to address the global climate change issue through a radical reduction of greenhouse gas emissions. Corporate resistance is still apparent in many cases.

The truth seems to be that the win-win situation prevails only in certain cases. Reducing environmental impacts through innovation results in production cost reductions and efficiency enhancement for corporate operations only for certain environmental problems during that phase of industrial development in which such opportunities are not yet exploited. According to Howes *et al.* (1997), corporate response to regulatory initiatives in developing positive environmental strategies has varied considerably in accordance with the environmental problem considered. Among the environmental problems for which they examined corporate responses in the United Kingdom, issues including CFC phase-out and contaminated land met with a positive response. On the contrary, corporate responses have not been positive on issues such as the reduction of greenhouse gases to meet climate change. In some cases, the environmental issue itself presents trade-offs. Air quality and transport is a case in point. Although innovations in vehicle technology over the last few decades have reduced emissions from individual vehicles, the increase in traffic has offset the supposed improvement in air quality. In addition to vehicle technology, any further response will need to address the transport system as a whole .

Environmental issues for which the solutions lie in the reduction of wastes or improved production efficiency through resource saving, present real win-win situations. Waste reduction in general and the reduction of certain toxic substances and energy conservation belong to this category. The positive corporate responses in fact pertained to these issues (*e.g.* the chemical industry's R*esponsible Care* programme), which will constitute the main current of corporate strategies in the near future. The popularity of the win-win argument in this decade reflects the fact that many firms have not yet identified and exploited the opportunities to enhance resource efficiency and reduce wastes in their operations. It may be noted, though, that win-win situations are limited and existing win-win opportunities are likely to be depleted sometime in the future. Even the proponents of the double-dividend argument clearly note that we are in that phase of industrial development in which such opportunities still abound (Porter and van der Linde, 1995). In order to exploit win-win situations to the maximum, companies need to know the exact cost and benefits of their environmental spending. This calls for the development and diffusion of improved environmental accounting methods.

In the current state of the art, as Howes *et al.* argue, it would be foolish to ignore the possibility of win-win situations, but it would be equally foolish to rely on them to create a more sustainable industrial sector. The possibility of the eventual depletion of such opportunities is likely to call for another shift in the long range in corporate as well as public policy strategy towards innovation and environmental sustainability. It is not easy to foresee what that change will be, but it is likely that with the emergence of newer technologies – information and communication technology, biotechnology, advanced materials and micro-scale technologies – for industry, there is little doubt that innovation will continue to play an important role.

The policy evolution in environmental regulations is characterised by increasing diversity. Technology specification based command-and-control type regulation is giving way to a more integrated approach involving increased use of economic instruments. Here again, as with the corporate response, the optimum policy response differs according to the environmental issue and according to the industrial sector. The basic issue facing public policy, as put forward by Schmidheiny (1992), is in "getting the prices right", that is, in achieving appropriate pricing of resources to reflect the environmental cost of their use. This is the only way to internalise environmental costs. Such a pricing structure will need to be one that can induce changes in the behaviour of consumers. This will be achieved mainly by designing suitable regulations that lead to appropriate pricing of resources through the use of economic instruments.

As discussed above, corporate decision making is rarely based on purely environmental considerations, or on the selection of cleaner technologies for their own sake, but involves larger efficiency considerations. In this context, in order to achieve environmental goals, public policy needs to be translated into an appropriate incentive structure for environmental innovations at the firm level. Incentives are a key element in public policy. Building incentives is one way to encourage industry to internalise environmental issues. Even for win-win situations, there is plenty of anecdotal evidence that companies only take action when there is public policy intervention. In the long range, developing innovative participatory approaches will also be important, with more environmental issues arising at the consumption phase.

The immediate policy challenge consists in the implementation of those policies that could correct market and systemic failures. Correction of market failure rests on designing appropriate regulatory regimes. A characteristic of environmental innovations as compared to other technological innovations is that they are normally induced by regulations. Regulations serve as "focusing devices" (Rosenberg, 1976) for environmental innovations. The fundamental role of environmental regulations in the near future is to correct the price signals which currently stifle environmental innovations. Such regulations need to induce firms to exploit win-win opportunities to the maximum. Where the environmental benefit involves a net cost, regulations need to succeed in putting in place an appropriate incentive structure for companies to pursue an effective environmental strategy.

Current policy instruments include environmental certification, labelling and "green" procurement. Recently, "greening" is extending into investment behaviour. Policy instruments also involve the use of traditional regulatory instruments as well as market-based instruments and need to be flexible to induce flexible responses. Also, regulatory regimes that stimulate participatory approaches (both inter-firm and public and private) to policy design and implementation are needed in the near future to address consumption-related environmental issues. Better regulatory co-ordination and coherence across different policy areas is an important consideration as is international co-ordination of regulatory regimes.

To correct systemic failures, policy designs need to address the increasingly complex, interdisciplinary and global nature of the current environmental challenge. This can be done by designing approaches that encourage co-operation across sectors. It would involve the government, universities and industry in research and development and technology diffusion. In general, environmental innovations often fall victim to systemic failure because of the complexity and the interdisciplinary nature of the problems to be addressed. The newer approaches to innovation currently on the agenda of technology policy makers, such as networking and clustering, are effective in addressing systemic failures in environmental innovation. Voluntary agreements are emerging as a policy alternative for those problems which present complex organisational challenges since they allow industry the maximum opportunity to structure solutions (Howes *et al.*, 1997). Partnership approaches are proving to be effective in inducing more suitable research and development efforts in developing and diffusing environmental technologies (OECD, 1999*a*).

VII. CONCLUSIONS

The initial preoccupation with end-of-pipe solutions led to the birth and growth of the environmental goods and services industry. An important challenge is to re-orient the sector as it exists today. For example, polluter industries no longer need large-scale desulphurisation equipment, but rather require new-generation production technologies fitted with sophisticated sensors and control equipment based on advanced information technology or with advanced processes involving biotechnology, advanced materials or micro-scale technology. This, in turn, implies a restructuring of the environmental goods and services sector as it has grown to date. It is conceivable that in addition to large engineering firms, the new sector would include specialised suppliers, including SMEs serving niche segments, in advanced information technology, biotechnology and other advanced techniques developed for environmental purposes. In this industrial context, closer supplier-client relationships are vital in developing relevant technology, and it is likely that innovative industrial clusters can arise. It is obvious that the environmental goods and services sector of tomorrow will be more research-based.

How do we move forwards as the win-win opportunities are eroded in the long range? What do we do in the face of increasingly unfamiliar environmental challenges like climate change and food security? How do we pursue technological dynamism? A useful policy tool to address these questions is technology foresight. Insights gained from recent foresight exercises in OECD countries indicate that in the medium to long term, environmental issues can be addressed through the use of emergent technologies for environmental applications. These technologies range from information technology, biotechnology and advanced materials to nano- and micro-scale technologies. The application areas range from agriculture, water treatment, waste and hazardous substance treatment and management, vehicle technology, construction, cleaner industrial processes and energy to monitoring global environmental changes. However, experts express profound uncertainty as to the prospects for realisation of such technologies through market demand (OECD, 1999*b*). Technology foresight can be designed so that demand and supply of environmental technologies are realistically matched.

Finally, a word about the view that environmental innovations may constitute a shift to a new technological trajectory or regime in the context of the long cycles mentioned earlier (Kemp, 1994; Freeman and Soete, 1997). The trend towards the internalisation of environmental considerations in corporate strategies and investment behaviour as well as of environmental costs in the economic system with accompanying effects on consumption behaviour, imply that the economic and social value system underpinning the current trajectory is changing. The sustainable development imperative is exerting a force to change the dominant technological paradigm and to shift the existing technological trajectories. Would this constitute a new upswing in the long cycles? The internalisation of environmental sustainability in the economic system will probably not constitute a new upswing separate from the ongoing one based on new technology, but could serve to reinforce it. The realisation of this depends very much on the implementation of appropriate and effective government environment and innovation policies.

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BIOTECHNOLOGY FOR INDUSTRIAL SUSTAINABILITY

Table of contents

This article was written by Michael Griffiths, consultant, and Salomon Wald of the Biotechnology Unit in the OECD's Directorate for Science, Technology and Industry.

I. INTRODUCTION

Since the beginning of 1999, biotechnology, and particularly the techniques of genetic modification, have become issues of worldwide concern and debate. In many OECD countries, governments are discussing these issues at cabinet level. Newspaper headlines speak of national and international conflicts, of impending trade wars, of growing public anxiety about the safety of genetically modified foods and crops, of protests by hostile non-governmental organisations. This is the context in which the G8 Heads of Government meeting in Cologne in June 1999, asked the OECD to "undertake a study of the implications of biotechnology and other aspects of food safety" and to submit its findings to their next summit meeting in 2000.

The focus of public interest is on food safety and genetic modification. In the current debate, it is sometimes forgotten that the applications of biotechnology go far beyond food and affect human health care, the environment and sustainable development in major ways.

The potential of biotechnology to contribute to sustainable development is vast and diverse. Biotechnology helps to remediate air, soil and water pollution, to modify animal and plant breeding as well as food production and to diversify energy sources. It is now beginning to penetrate industrial manufacturing technologies.

The prospect of radical changes in agro-food technologies has emerged as the most controversial aspect of biotechnology. While this is not the place to discuss the underlying reasons, it should be noted that the controversy is also reflected in different, conflicting notions of "sustainability".

In the view of many scientists and food companies, biotechnology, particularly gene technology, is making agro-food production more "sustainable". It increases productivity and output while decreasing inputs of agro-chemicals, for example, which are a major environmental burden. In contrast, opponents of modern agro-food biotechnology fear the suspected negative side-effects of genetically modified organisms on health, on the environment, on traditional social structures, or on trade and employment. In their eyes, this new technology is not yet "sustainable".

The main advantage of industrial over agricultural biotechnology is that its definition is clearer and its contribution to sustainable development is easier to measure and quantify in the industrial manufacturing process. While it still has to cross many scientific, technological, economic and regulatory hurdles, its contribution is not disputed and has not given rise to public controversy.

Industrial biotechnology replaces traditional catalysts and transformation processes – many of them very polluting – by newer, environmentally friendly ones. These are based on living organisms or parts thereof: biocatalysts and enzymes. Industrial biotechnology aims at reducing production inputs, such as raw materials and energy, and at eliminating or at least reducing waste generation.

This article shows that genetic modification is an essential and extremely powerful tool for developing new and better biocatalysts (through recombinant DNA technology). It also shows that the food industry is a sector where biocatalysis is being introduced for the sake of cleaner (and sometimes cheaper) production. This has not led to public hostility, in part because the general public is little aware of manufacturing processes inside industry, but also because the goal of cleaner industrial production is very popular among all stakeholders, including consumers. In addition to the environmental benefits, incorporation of industrial biotechnology into manufacturing processes will enhance the economic competitiveness of companies and industrial sectors. This is why more and more industries are paying attention to these technologies.

Industrial biotechnology could be a success story, not only from an economic and technological perspective, but also in terms of public attitudes towards the new technology. Will this influence the debate about other applications of biotechnology? Will it help to reduce public apprehensions about the impacts of the technology? Only time will tell.

II. BIOTECHNOLOGY FOR INDUSTRIAL SUSTAINABILITY

The dilemma of sustainability

Human activities – industrialisation, urbanisation, agriculture, fishing, forestry and mineral extraction – have profound impacts on the world's environment and on environmental sustainability. There is growing awareness that resource management – nationally, regionally and globally – needs to be improved and the amounts of wastes and pollution reduced. All signatory countries to the Rio Declaration on Sustainable Development agreed to reduce, and if possible eliminate, unsustainable patterns of production and consumption.

What sustainability and sustainable development mean is rather elusive: The World Commission on Environment and Development has defined sustainable development as: "strategies and actions that have the objective of meeting the needs and aspirations of the present without compromising the ability to meet those of the future". The difficulty with such a broad definition is that it lacks operational guidance for those who wish to achieve this goal. Consequently, it is necessary to address questions such as:

– Which current activities are consistent with sustainable development?

– What policies are required to achieve sustainable development?

– What contribution can science, and particularly biotechnology, make?

To industry, sustainable development means continuous innovation, improvement and use of "clean" technologies to make fundamental changes in pollution levels and resource consumption. Because all stages of a product's or process's life cycle may affect the environment, design principles that consider all stages of a product, from selection of raw materials to improvement of recovery during waste management, must be employed to reduce environmental impact. An environmentally friendly process would, in principle, consume little energy and non-renewable raw materials (especially fossil fuels) and reduce or eliminate waste (including material and energy recycling and energy use).

In the 1960s and 1970s, concern over the environment centred primarily on issues such as point-of-source pollution, dissemination of pesticides, air pollution in certain cities, and oil pollution at sea. Biotechnological options were considered for waste treatment, and commercial applications were used both for end-of-pipe disposal and bioremediation. A major change in approach has taken place since the late 1980s; the emphasis is no longer on removal of pollutants from an already damaged environment but on the need to reshape industrial process technologies to prevent pollution at the source. Technologies for waste minimisation or prevention have gradually emerged, and the challenge for biotechnology has been to provide tools appropriate for industrial sustainability. Recycling of materials, minimisation of energy use, retrofitting of existing industrial processes to alleviate pollution, and applications of innovative science have provided routes to clean or cleaner technology.

Industrial biotechnology, which uses biological systems such as whole organisms and biological catalysts (enzymes) to produce goods and services, has come of age. Micro-organisms have been used to "manufacture" foodstuffs since prehistoric times, industrial fermentation dates from the last century and the biological production of antibiotics, for example, began in the second quarter of this century. Modern biotechnology expands these opportunities by building on recent gains in our understanding of genetics and the relationships between biological structure and function. Unlike the earlier, traditional biotechnology, modern biotechnology makes use of recombinant DNA technology, otherwise known as genetic engineering. However, biotechnology is broader than genetic engineering; it draws heavily on process technology, chemistry and classical engineering.

Biotechnology is already playing an important role in a growing number of industrial sectors because of its clear environmental advantages and its economic competitiveness. For a given level of industrial production, consumption of material and energy can be reduced and less pollution and waste generated. Why then have clean technologies not been more widely adopted? Many reasons have been given: end-of-pipe treatments remain cheaper options; regulatory authorities continue to be preoccupied with the symptoms rather than the causes of pollution; the pay-back period for investment in clean technologies seems too long; existing plant needs to be amortised; basic information is lacking; the cost-effectiveness of new technology is uncertain; and, in some case, there is a lack of the necessary clean technology.

For the first time, an overall picture of how modern process biotechnology penetrates industrial operations is emerging. The pattern seems to be the typical S-curve that describes the adoption of any new technology: a slow initial induction phase of perhaps a decade is followed by a period of rapid growth lasting about two decades and then by a mature phase of slow growth. Many biotechnological applications are spread over many different industries. Some have been known for more than five years, others perhaps for as many as ten. There are certainly niches in which industrial biotechnology affords clear benefits, both economic and environmental, over other technologies, and no major barriers to continued success have yet been perceived. At the same time, the power of the tool itself continues to grow, and in the end it is this capacity for self-improvement that encourages the belief that biotechnology will have a very significant impact on industrial sustainability.

The problems facing industry

Many current industrial products and processes are environmentally unfriendly, and some are major sources of pollution. All stages of a product's or process's life cycle may affect the environment by using up materials and energy or by creating waste. Any substitution which reduces raw material consumption or waste production by recycling materials, for example, is more environmentally friendly or "clean". The crucial feature of clean technology is that it shifts attention and action from remediation to prevention of environmental degradation, and this forms the basis for industrial sustainability.

Biotechnology embraces a wide range of techniques, and no single one can be applied to all industrial sectors. Because of its versatility, many industries that have not yet used such technologies are exploring the possibility of doing so. Some patterns of use suggest that they can have an important economic impact. However, certain problems for industrial applications have, until recently, outweighed the advantages. The entrenched infrastructure in industries that have relied on physical and chemical technology, for instance, presents a significant challenge to the widespread adoption of new biotechnology.

Public pressure is a potent force for change over a broad spectrum of environmental issues, and companies may find that establishing environmental legitimacy has strategic importance for industry. The public has often taken a negative view of industry, one that is perpetuated by concerns about its unfavourable environmental record, hazards associated with manufacture and transportation, and generation of waste. Chemicals manufacturing, for example, is seen as a major consumer of energy and non-renewable resources and a major producer of solid, liquid and gaseous waste. In terms of environmental impact, the use of bio-based resources as feedstocks as well as biological processes in the large-volume sectors of the industry would be a positive step. The chemical industry has in fact taken initiatives to promote clean products and processes.

Another reason for the slow penetration of biological processes is more sociological in nature. The traditional training of chemical engineers and chemical plant designers has not included the study of biological processes. The nature of the materials, vessels and operating conditions are so different that engineers and plant operators need to be retrained to gain the confidence they have with more traditional processes.

One might assume that reduction of raw materials, energy consumption and wastes are clearly translatable into cost reductions. However, as novel processes often require high capital expenditure, process development costs may outweigh reductions in operating costs. Conventional processing plant is built to operate for many decades and a novel process has to show a positive return when compared to the low costs of a fully depreciated plant (Box 1). Biotechnology's slow penetration of the industrial chemicals sector suggests that the current overall economic advantage of biotechnology-based processes is not enormous and that its environmental advantages alone have not sufficed to drive their rapid adoption over existing chemical processes. Nevertheless, its use continues to spread, and the trend is clearly towards adoption of biotechnological tools in conjunction with conventional chemical tools to develop economically competitive new processes.

The multifaceted nature of biotechnology may make it difficult to assess its relative importance in different industrial sectors. In the paper industry, for example, biotechnology makes it possible to breed superior pulp trees with lower or different lignins, altered fibre structure and higher yield, thereby improving paper quality and throughput. Biopulping helps release wood fibres, and enzymes improve water drainage when drying. This results in better paper quality (colour fastness, strength) and lower energy consumption for a given throughput. Biological de-inking will replace mechanical de-inking with an as yet unquantified energy saving, and biobleaching is replacing the use of environmentally unfriendly chemicals. Enzymatic biofilm removal reduces manufacturing down time and reduces costs. The use of such technologies, allied with biological water treatment, means that some paper mills now recycle 100% of their water.

Box 1. **Is biotechnology a feasible alternative?**

Technical questions that an industrial manager might ask include:

– Is it possible to improve our process, or a competitor's process, using biotechnology?
– Can we adapt the biology to our process or will we have to adapt to it?
– Are the biological systems available now or is further R&D necessary?
– Do we have to change our whole process or just one step?
– Can we incorporate a new biocatalyst to replace a conventional one and will this need radical bioprocess re-design?
– Can we use conventional organisms or biocatalysts or do they need to be genetically manipulated?
– If so, can they be contained and will the public accept our process and the final product?

Clearly, energy, environment, costs, quality, productivity and regulatory factors may all drive biotechnological innovations. The most important factors are likely to vary, depending on the industry: in the case of paper, these have been the need for higher productivity and increasingly stringent regulations.

Biotechnology: an enabling technology

To meet the goal of reduced consumption of energy and materials and lower production of wastes and emissions, biotechnology must compete with chemical and physical engineering approaches. While it is but one type of technique for achieving clean industrial products and processes, it is now so versatile that it is reasonable to seek biotechnological solutions. It has the advantage that it builds on biological systems that have evolved over many millions of years and are continuously self-improving. Moreover, living systems manage their chemistry more efficiently than man-made chemical plants, and the wastes generated are recyclable and biodegradable. Enzyme-based processes operate at lower temperatures and produce fewer and less toxic waste by-products and emissions than conventional chemical processes. However, it must be kept in mind that biotechnology *per se* is not necessarily clean, just as chemical technology is not invariably dirty. Valid comparisons of competing technologies or processes can be made only through carefully designed life cycle assessments or similar objective criteria.

Biotechnology represents a wide-ranging set of tools, which can be used to improve large-scale fermentations to produce chemicals such as ethanol, at one end of the spectrum, to using minute parts of biological molecules as sensors in analytical devices at the other. The power of biotechnology to alter the characteristics of living organisms and their constituent parts is so great that many industries are actively investigating the opportunities. R&D is already providing a steady stream of creative innovations.

One group of tools is composed of biological catalysts, which include living organisms and their catalytically active constituents, particularly enzymes. Biocatalysts are generally more specific and more selective than their non-biological counterparts and capable of yielding fewer by-products (specificity), and using less purified raw materials (selectivity). Although biocatalysts offer advantages, they also present a number of problems for industrial applications, and these have often outweighed the advantages. Major difficulties have included the fragility of the molecules, the need for large amounts of water, and high cost. Many of these problems have been addressed and overcome using new designs of bioreactors and improved catalysts.

Integrated bioprocessing is proving to be another way to bring biocatalyst activity into mainstream processes by using procedures for partitioning the catalysts and the reacting materials. This simplifies the overall process by reducing the number of stages. An interesting recent example is the simultaneous breakdown and fermentation of cellulose to glucose, using enzymes. The glucose is removed by fermentation to ethanol with yeast in order to prevent feedback inhibition of the cellulose hydrolysis. Ethanol, in turn, depresses the fermentation rate and is extracted using a water-immiscible solvent, oleyl alcohol. All these reactions take place in a single reactor vessel.

As an enabling technology, biotechnology is proving its worth in many areas. In the petrochemicals industry, for example, use of biotechnology can clearly lower the production of pollutants. Cheap fossil fuels powered the industry's development, but environmental concerns are encouraging attention to bioresources and use of biorenewable feedstocks, as they can result in processes that do not increase the atmospheric build-up of carbon dioxide (CO_2). Biofuels, such as bioethanol, can also help alleviate atmospheric pollution problems. Because biomass, as it grows, consumes CO_2, substances made from biological raw materials are a zero net contributor to atmospheric greenhouse gases, unless fossil fuel is used in their manufacture. Chemists have long sought to duplicate plant materials and it may now be environmentally advantageous to return to plants to obtain chemicals. Starch, cellulose and vegetable oils and proteins are all potential alternative raw materials for industrial production, and a parallel universe of chemicals and structural materials may be developed from biological raw materials. These range from biodegradable plastics, biopolymers and biopesticides to novel fibres and timbers. As for biofuels, these have not been more widely exploited largely for economic reasons.

The soya bean is another example of an important renewable resource that biotechnology has made even more valuable. Its versatility as a raw material ranges from food products and diesel fuels to polymers, fabric softeners and solvents. It was used to develop several hundred industrial products in the 1930s and 1940s, including adhesives, linoleum, rubber substitutes, printing inks and plastics. Recent advances in recombinant generic biotechnology have made it possible to alter the lipid composition of soya beans and to increase the variety of biohydrocarbons available. Amides, esters and acetates of these biohydrocarbons are currently used as plasticisers, blocking/slip agents and mould-release agents for synthetic polymers. Biohydrocarbons linked to amines, alcohols, phosphates and sulphur groups are used as fabric softeners, surfactants, emulsifiers, corrosion inhibitors, anti-static agents, hair conditioners, ink carriers, biodegradable solvents, cosmetic bases and perfumes. Complexes with aluminium and magnesium have produced greases and marine lubricating materials.

The most renewable of renewable raw materials is of course carbon dioxide itself. Biotechnology has made it possible to produce fats from algae for biodiesel fuels and the antioxidant vitamin β-carotene. Though algae-derived biodiesel has only been produced at laboratory scale and β-carotene production worldwide is only 10 tonnes a year, biological systems have the potential to produce many different oxygenated chemicals from CO_2. A conservative estimate indicates that CO_2 usage could easily be expanded by orders of magnitude if new or improved processes could be developed.

III. BIOTECHNOLOGY AT WORK IN INDUSTRY

New products from industrial biotechnology include more functional products, such as biodegradable polymers, optically active chemicals and enzymes for use in detergents and feeds. The more sophisticated chemistries enabled by biocatalysts lend themselves to "smarter" products such as biopolymers that bring more functionality to the consumer for approximately the same cost as the products they displace.

Major industries around the world are now using biotechnological processes to improve their efficiency, cutting down on waste, materials and energy. Among them are chemicals, pulp and paper, textiles, food and feed, metals and the energy industry itself.

Chemicals

The "chemicals" sector comprises commodity chemicals, plastics, pharmaceuticals, speciality and fine chemicals, and enzymes. Chemical manufacturing is a major producer of materials, a major consumer of energy and non-renewable resources, and a major contributor to waste production. In the United States, for example, chemicals have accounted for about 18% of all manufacturing (based on sales) for the last 20 years.

It has been approximately ten years since the Nitto Chemical Company of Tokyo switched from a traditional chemical process to a biotechnology-based process for producing polymer-grade acrylamide. Commodity chemicals currently derived largely from plant matter in the United States include ethanol (3.8 million tonnes a year), cellulose esters and ethers (0.5 million tonnes a year), sorbitol (0.19 million tonnes a year) and citric acid (0.16 million tonnes a year). This sector employs both chemical and biotechnological approaches and is an excellent example of the impact of biotechnology. Efforts to produce other commodity chemicals such as succinic acid and ethylene glycol (currently made almost exclusively from petrochemical feedstocks) using new processes and renewable resources are in the pilot stage in public-private, government-sponsored partnership programmes. Various other parts of the chemicals manufacturing industry have begun to experiment with the new tools offered by biotechnology. While biotechnology-based processes still produce relatively few bulk (commodity) chemicals, it has been adequately demonstrated that they can be scaled up to the level needed. Although it is not certain that bio-based manufacturing will always be cleaner, it is safe to say that wastes from bio-based manufacturing will be more compatible with conventional wastewater treatment systems.

Micro-organisms can synthesise a wide range of compounds, using carbohydrates as their sole sources of energy and carbon. Companies are exploiting these capabilities to obtain speciality chemicals. One such chemical is indigo, which is used to dye denim. In ancient times, indigo was obtained from plants, but over the last century, it has been synthesised chemically from toxic chemicals, including aniline, formaldehyde, and sodium cyanide. Through bio-engineering, a strain of the micro-organism E*scherichia coli* (E. *coli*) has been created that produces substantial amounts of tryptophan, converts it to indole, and finally to indigo. Indigo produced by E. *coli* will soon be on the market, competing with dye synthesised by the older industrial method.

The fine chemicals industry is one of the industrial segments where the impact of biocatalysis has been most strongly felt. In part this is due to the ready acceptance of enzymes by organic chemists and the low entry barrier, *i.e.* low level of investment, for new technologies in this small-scale industry. Despite a four-fold increase in chemicals output, biocatalysis has reduced waste production by 20%. While biocatalysis is the major contributor to cleaner production in this sector, reduction and reuse of solvents has also contributed to more environmentally friendly production processes.

Biotechnology has also improved the production of certain crop protection chemicals, such as glyphosate. The DuPont Company has announced a new process for producing this broad-spectrum herbicide, using enzymes cloned from spinach and yeast to create a catalyst capable of oxidising glycolic acid to glyoxylic acid. This reduces the number of steps in the overall process and the loss of product to waste streams.

Allied Colloids Limited is developing an industrial-scale bioprocess for making ammonium acrylate, a key component of many polymers used in industry, for thickening paints and as adsorbents and coatings. Current methods of producing ammonium acrylate involve the hydrolysis of acrylonitrile to acrylic acid, which is then reacted with ammonia. The process is very energy-intensive and creates a by-product which is expensive to remove.

The manufacturing of isopropyl myrisate, an ingredient in cosmetics, has been transformed by the introduction of a biocatalyst developed by Unichema. The process uses a naturally occurring enzyme, lipase, as the catalyst. Lipase normally hydrolyses fats and oils. By removing water, Unichema has reversed the reaction to make isopropyl myristate from its constituents, a process known as esterification. This technique has several advantages. Mild reaction conditions lead to a cleaner, odour-free product; yields are improved and the specificity of the enzyme is such that the product has the high purity needed for materials used in cosmetics.

Pharmaceuticals

Today, many pharmaceuticals are semi-synthetic molecules, in that part of their structure is synthesised by a living organism and is then modified by chemical processing. Modern advances in biotechnology contribute to cleaner production of semi-synthetic antibiotics by biocatalysis, optimised fermentation, and replacement of organic solvents by water. For instance, by replacing a chemical reaction in the solvent methylene chloride by an enzymatic step in water, total use of methylene chloride can be reduced by about 25 000 tonnes. The recent design of thermostabilised enzymes and the development of a new bioreactor process by Kaneka Corporation have enabled the production of 2 000 metric tonnes a year of a side chain for the production of the antibiotic, amoxicillin. This all-enzymatic process has displaced an older one in which part of the synthesis was carried out chemically. The chemical part of the process had several problems, including colouring of the product, formation of by-products, and low energy efficiency.

Pulp and paper

The pulp and paper industry is very capital-intensive with small profit margins. To keep up with the increasing demand for pulp and paper and to meet increasingly stringent environmental regulations, the industry has been constantly looking to technological improvements. Driven largely by market and environmental demands for less chlorinated products and by-products, the pulp and paper industry is cited as the fastest-growing market for industrial enzymes. In the United States, it is projected to grow by 15% a year for the next ten years.

Several processes are used to separate the cellulose fibres from the lignin in wood to form a slurry (pulp) that is further processed into paper and board. Chemical pulping operations are particularly polluting; biopulping, which involves treating lignocellulosic materials with lignin-degrading fungi, has been shown to result in energy savings and improved strength. The structure and chemical composition of pulp fibres are of paramount importance for paper strength and other properties. Enzymes can reduce fibre coarseness and increase paper density and smoothness. The speed of paper machine operation depends in part on the rate at which water drains from the pulp mat, and drainage rates tend to be lower for recycled fibres, leading to a decrease in production rates as the recycled fibre content increases. Enzymes such as cellulases and hemicellulases can improve the drainage rates of recycled fibres. Pilot and mill-scale testing have led to commercial use of these enzymes as drainage aids.

The Kraft process accounts for most of the world's pulp production. Kraft pulps, however, have a characteristic brown colour, which must be removed by bleaching before manufacturing paper for printing and writing or other products in which appearance is important. Chlorination has traditionally been used, but pulpmakers are turning to other techniques because of consumer resistance and environmental regulations. Studies conducted in Finland show that hemicellulases (mainly xylanases) enhance pulp bleaching, and these enzymes are now being used commercially in Scandinavia, Canada, the United States and Chile. A new enzyme that is better suited to the temperatures and pH found in pulp processing has been developed in Israel and successfully tested in a large-scale paper mill trial. The treatment of Kraft pulps with xylanases leads to significant reduction in chemical consumption with almost no loss in pulp yield or quality.

The enzymes that partially break down cellulose are one of the key advantages that biotechnology offers the paper industry. They remove the finest fibres, thereby allowing water to drain away faster, cutting processing time and reducing the energy required to dry the paper. Machine speed can be increased by up to 7% and energy input per tonne of pulp reduced by as much as 7.5%.

Textiles

Driven by globalisation and consolidation, the textile industry is undergoing significant changes, and new technologies are crucial to success. Consequently, the industry is seeking new sources of innovation, of which biotechnology is one. At present, the global market value of textiles is around USD 672 billion, while in 1996 the global enzyme market for textiles was USD 178 million.

Biotechnology offers the opportunity to produce fibres with improved or novel features, such as Agricetus' genetically engineered cotton, which contains a bacterial gene that makes a polyester-like substance. The fibre is reported to have the texture of cotton, but to be much warmer. Microbial production of fibres has also received significant attention. Zeneca has produced a naturally occurring polyhydroxybutyrate (PHB) by bacterial fermentation and Monsanto is now investigating genetically engineered plants for production of PHB. Weyerhaeuser has already commercialised bacterially derived cellulose that is finer, more uniform, and more resilient, and Sony has developed stereo speaker cones and diaphragms from bacterial cellulose.

DuPont and Genencor have developed a microbially based fermentation process for the manufacture of 1,3-propanediol, a key ingredient in polytrimethylene terephthalate, a polyester that is superior to the widely used polyethylene terephthalate (PET), but which was previously too expensive to make in large amounts. The organism is engineered so that the carbon flow or pathway is optimised for the production of the 1,3-propanediol.

Although enzymes have been used in textile processing since the early part of this century to remove starch-based sizing, it is only in the past eight to ten years that serious attention has been given to the investigation of enzymes for a wide range of textile applications. One very successful area has been the use of cellulases for the stonewashing of denim. Here, enzymes are used in place of or in addition to pumice stone to create denim garments with a "worn" or faded look. The "biostoning" of denim with enzymes is an example of an environmental benefit, and enzymes are expected to have an even greater impact on effluent quality as more fibre preparation, pre-treatment and value-added finishing processes convert to biotreatment. Since enzymes are very effective catalysts even under mild conditions, they do not require the high energy often associated with chemical processes.

Cellulases are also gaining widespread use in the production of the relatively new fibre, lyocell, the generic name for solvent-spun cellulosic fibres. Compared to other man-made fibres (such as rayon), lyocell has greater strength and a more environmentally favourable manufacturing process. However, the fibre tends to fibrillate during processing. This fibrillation is unique to lyocell and can be controlled by cellulase treatment to achieve a soft, luxurious fabric and laundering fastness.

Textile and apparel companies are spending more time and money on the environment. Regulatory pressure is expected to intensify as new technologies that offer alternatives to pollution and waste prevention become available.

Leather

Hides and skins contain proteins and fat in between the collagen fibres. Prior to tanning, these substances have to be partly or totally removed, a process formerly carried out with organic solvents but now more often with protein- and fat-dissolving enzymes. Preparation requires proper soaking of the raw material to obtain good quality leather, but as some raw materials are stored dry, satisfactory rehydration may be a difficult and time-consuming process. By using protease and carbohydratase enzymes to degrade protein and carbohydrates, water absorption is significantly improved and the soaking operation shortened.

The conventional way to remove hair requires harsh chemicals such as slaked lime and sodium sulphide which dissolve the hair completely and open up the fibre structure. Enzymes can reduce the chemicals needed and, in addition, produce a better, cleaner product, a higher area yield and fewer chemicals in the wastewater. In particular, the hair is not dissolved but can be filtered out, thereby reducing the chemical and biological oxygen demand of the waste.

In order to make leather pliable, it must be treated before tanning in a process known as bating, in which certain protein components are dissolved and can be washed away. The degree to which bating is applied depends on the desired softness of the finished product. Traditionally, dung was used as a bating agent, but in 1908 the German chemist Otto Röhm patented the first standardised bate based on pancreatic enzymes. Today, both bacterial proteases and trypsin (the traditional pancreatic protease) are used for bating, although fungal and plant enzymes have also been tried.

Enzymatic degreasing of sheepskins is a recent introduction. Sheepskins have a world market share of about 30% of leather manufacturing. The enzymatic degreasing process replaces a paraffin solvent-based process and is therefore more environmentally acceptable. Moreover, the recovery and reuse of paraffin involves high investment and running costs. Aside from its environmental benefits, therefore, enzymatic treatment also results in improved quality of the end product and reduced costs. The enzymatic process gives a product with improved tear strength and a more uniform colour and a cost reduction of at least 25%, depending on the plant's operational practices. The biotechnological process has a market penetration, worldwide, of 30-50% with large-scale applications in Australia, England and France.

Food

In this sector, environmental considerations are more subtle, as these materials are made from renewable resources. It is therefore necessary to balance the environmental impact of commercial agriculture with that of alternative production routes, for example, via growth of micro-organisms in a fermentor or from fossil fuel feedstocks.

Industrial aspects of food production, such as the manufacture of food additives, closely resemble those of other chemicals. Food additives include gums, emulsifiers, vitamins, minerals, preservatives, leavening agents, acidulants, flavours, and colours.

Consumer preferences for “natural” products give biotechnology-derived additives an advantage over chemically synthesised ones, if their cost is competitive. Examples of established biotechnology-derived additives include xanthan gum from *Xanthomonas campestris* and citric acid from *Aspergillus niger*. One of the most discussed potential applications is the production of natural flavours (like vanilla) by plant tissue culture, although this has not yet had a commercial impact. Combinations of glucose oxidase and other enzymes are being used to replace potassium bromate as an oxidant in flour for bread making because of concern about bromate’s possible carcinogenicity.

Fermentation-derived preservatives are another promising category. Most traditional food preservatives are chemically synthesised fatty acids or other organic acids that increase food acidity and inhibit broad categories of micro-organisms. One trend is the development of fermentation-derived preservatives like “Upgrade” (developed by Stauffer Chemical and now produced in the United States by ICI’s Quest unit) with the same active ingredient (propionic acid) found in chemically derived calcium propionate. Other fermentation-derived preservatives, like Delvocid (pimaricin), produced from *Streptomyces natalensis* by the Dutch company Gist-brocades, or nisin, produced from *Streptococcus lactis* by the Australian company, Burns Philp, have unique characteristics or applications. Chemicals like nisin are of particular interest because they can be produced by “friendly” lactic acid bacteria and are effective against especially challenging pathogens like *Listeria*.

The environmental benefits of producing food additives by fermentation or enzymatic routes instead of traditional organic synthesis are similar to those for other speciality chemicals. In the case of fermentation-derived preservatives, there is an even more favourable effect when the fermentation broth is incorporated in the finished product. The most desirable situation involves the use of bacteriocin-producing cultures *in situ* for fermented foods (like sausage or sauerkraut), where they consume unstable carbohydrates, naturally preserve the finished product, and contribute nutritive value of their own.

Starch processing involves the conversion of corn or another grain into dextrose and other syrups by a hydrolysis reaction. This was formerly done using acid at high temperature and pressure, but dextrose yields were limited to about 80%, and the process was hazardous and expensive and produced large quantities of salt as a by-product. The initial change to enzymatic hydrolysis in the 1960s increased dextrose yields and eliminated the drawbacks of the acid process. In the 1970s, development of immobilised glucose isomerase enzymes enabled the production of high fructose corn syrup. In the 1980s, thermostable alpha-amylases contributed to increased yields, and in the 1990s, recombinant thermostable amylases contributed to reduced costs.

One application with very great potential environmental benefit is the use of biotechnology to convert waste streams from one process into raw materials for another, or to upgrade under-utilised raw materials into a more valuable form. Ideas abound, including alternative uses for the grape pomace left over from wine making, corn cobs as a substrate for citric acid production, and cranberry waste as a substrate for fungal bioinoculants. The dairy sector is especially promising, as large quantities of whey are produced in cheese making. One successful approach has been the production of lactose-fermenting yeasts as flavouring ingredients.

Animal feed

Modern biotechnology plays a significant role in the production of micro-ingredients for the feed industry, but in terms of volume and sales, chemically synthesised products have the major share of the total market. Since the common protein sources used in animal feeds (*e.g.* soya, fishmeal, wheat and maize) are deficient in methionine, lysine, threonine and tryptophan, these essential amino acids are added as supplements to monogastric diets, *e.g.* for poultry and pigs. Whereas methionine is produced by chemical synthesis (300 000 tonnes in 1996), lysine, threonine and tryptophan are produced by industrial fermentation using mutants of C*orynebacterium glutamicum* and recombinant strains of E. *coli*.

Feed enzymes are designed to degrade components of feed raw materials that limit digestibility and/or lead to a higher level of manure, nitrogen and phosphorus excretion. The best-known examples of feed enzyme products are based on endoxylanases and phytases. Endoxylanase enzymes hydrolyse certain compounds present in wheat and maize, thereby increasing digestibility of all nutrients and reducing output of manure, nitrogen and phosphorus. Phytases hydrolyse phytic acid and release inorganic phosphate, thereby both avoiding the need to add inorganic phosphates to the diet and reducing phosphorus excretion.

L-carnitine, an essential cofactor in the transport of long-chain fatty acids, is a significant new product for intensive animal production. A new biotechnological process developed by LONZA provides a rare comparison of waste generation by chemical and biotechnological processes producing the same product. The latter is a much cleaner biotechnological process, which produces about 50% less total organic carbon waste than the chemical process and less than 25% of the wastewater.

Metals and minerals

Biotechnology for mining and metals recovery includes the use of micro-organisms for bioleaching and minerals bio-oxidation. These processes are employed worldwide by the mining industry for the extraction of base and precious metals and use bacteria, principally T*hiobacillus ferrooxidans* and L*eptospirillum ferrooxidans* and certain thermophilic (high-temperature) bacteria, to leach metals such as copper and gold from a sulphide mineral.

While the cleanliness of bioprocesses compared to conventional metal recovery methods has not been well established and would benefit from life cycle analysis (see below), copper recovery companies that use bioleaching report advantages over conventional roasters, smelters, and pressure autoclaves. These include: no noxious gases are produced (roasters produce As_2O_3 and SO_2, which must be contained); shorter construction time; environmental permits are acquired more rapidly and environmental reporting is less onerous; no toxic effluents are produced; iron arsenate residue is environmentally stable; metal recovery is excellent; operation is simple and safe, as processing is at ambient temperature and pressure; smaller projects can be developed economically and have a higher net present value.

The galvanising industry provides a good example of the use of biotechnology in clean production. Landskrona Galvanoverk in Sweden has designed a biotechnological process for metal finishing to replace the traditional alkaline degreasing process, which uses 5% sodium hydroxide at pH 11-14. The alkaline process, which creates a large volume of wastewater containing heavy metals, has been replaced by an enzymatic degreasing process. The new process, which has also been implemented in two other galvanising companies, produces half as much sludge and uses a tenth the quantity of water. In addition, there is a cost saving which is expected to have a simple payback time of five years.

Energy

Biotechnology is having a major impact on the economics and environmental impact of the energy sector. The effect of genetic engineering will eventually be considerable. Biotechnology can produce cleaner coal and petroleum, chiefly by removing sulphur and thus reducing the release of environmental contaminants during combustion. The production of low sulphur fuels will extend fossil fuel reserves and reduce levels of air contaminants. Biotechnology also has the potential to produce equivalents to petroleum distillates, such as biodiesel. Ethanol, methane, and molecular hydrogen are even cleaner fuels, all of which, when produced biologically, would result in greatly lowered levels of greenhouse gases.

Bioethanol is a liquid transportation fuel. Over a 20-year period, the yield of bioethanol in the United States from agricultural waste alone could meet current gasoline demand in energy terms. Most bioethanol is made from sugar cane, corn and other starch crops. In the United States, approximately 3.8 billion litres of ethanol are produced annually, and production in Brazil may be four times that. However, a tax credit is needed to achieve a competitive market price. To be economically competitive with fossil fuels, the technology for producing ethanol from biomass-derived sugars will require using high-yield, low-cost crops and more efficient methods of converting lignocellulosic waste material into fermentable sugars. These two areas are the focus of current research.

The bioconversion of synthesis gas to liquid fuels such as methanol is also being investigated. Synthesis gas is a mixture of carbon monoxide, hydrogen gas and CO_2 made by the partial oxidation of any carbon-based material. Feeds for the production of synthesis gas include agricultural, municipal, and paper wastes and biomass grown specifically for this purpose. The range of feeds for synthesis gas makes it a particularly versatile source of fuels. With potentially lower processing costs and greater carbon yield, fuels derived from synthesis gas are an attractive alternative to fuels produced by fermenting biomass-derived sugars.

Sulphur must be removed from fossil fuels because the combustion of sulphur molecules in coal and petroleum products leads to the production of sulphur oxides, which in turn are the source of acid rain. Biodesulphurisation is intended to replace an existing process (hydrodesulphurisation) which is expensive, energy-intensive, and inadequate for the deep desulphurisation of fuel that will increasingly be required as low sulphur crude becomes scarcer and regulations become more stringent.

Scientists involved in studies sponsored by the US Department of Energy are targeting a procedure known as simultaneous saccharification and fermentation for converting cellulose to ethanol. The process combines the cellulose hydrolysis and fermentation steps in one vessel to produce high yields. The objective is to develop technologies for producing ethanol from biomass at a cost that will be competitive, without tax incentives, with the cost of gasoline.

IV. MEASURING INDUSTRIAL SUSTAINABILITY: HOW CLEAN IS CLEAN?

There is a range of "tools" for measuring the effect of technology on the environment. Of these perhaps the best is Life Cycle Assessment (LCA), which is a way of evaluating alternative products and processes. LCA can be used over the entire life cycle of a process or product – from the "cradle to the grave" – irrespective of how the product is made or disposed of.

Adoption of life cycle concepts encourages companies to look systematically at products throughout their lifetime rather than on the manufacturing stage alone. This type of analysis offers a way to:

- Decide whether a process, product or service is in fact reducing the environmental load or merely transferring it upstream to resource suppliers or downstream to treatment or disposal.
- Determine where in a process the most severe environmental impact is created.
- Make quantitative comparisons of alternative process options and of competing technologies.

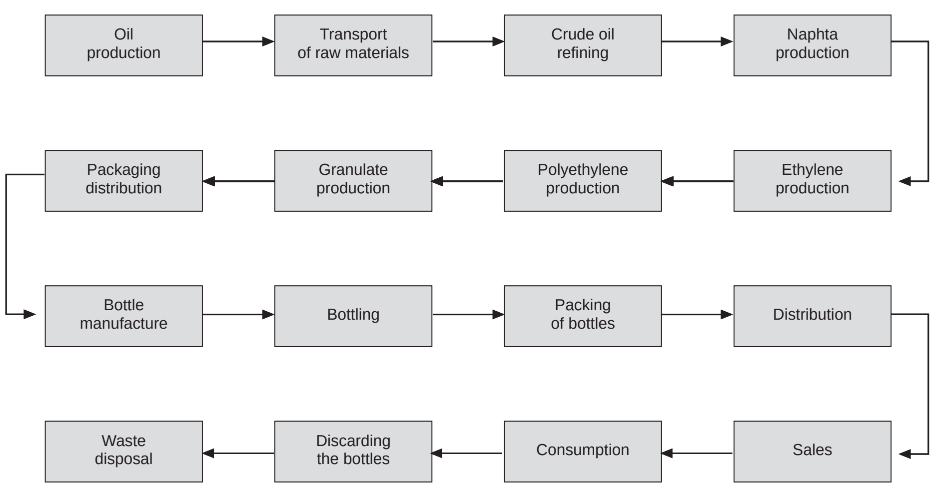
If industrial products and processes are to be subjected to a critical appraisal from the viewpoint of sustainability, the attractiveness of LCA lies in the use of the life cycle concept for products/systems, the description of impacts on the ecological system, the possibility of objective or fair comparisons of ecological systems, and easier objective communication of ecological problems.

However, LCA studies also have limitations. For example, LCA is confined solely to the energy and material balances. Socio-political and economic criteria, however important they may be to decision makers, fall outside its scope. Also, assessments cannot evaluate parameters such as availability and renewability of raw materials, or compare products produced for different purposes and/or under different conditions. In particular, they do not remove the need for decision making.

An exhaustive analysis of a product's life cycle has to take into consideration not only the mass and energy flows linked to raw materials acquisition and production processes, but also those related to transportation, use and disposal. Figure 1 shows, for example, the many elements in the life cycle of a relatively simple product such as a polyethylene bottle.

LCA should ideally be performed in the project's early stages, when it can help determine the environmental benefits of a clean process. Simple decision-making

Figure 1. **The life cycle of a polyethylene bottle**



Source: SETAC 93.

rules are needed to establish the *boundaries* of an LCA (where the process that is being analysed begins, and where it ends) and the *weightings* (relative importance) of the factors included in the analysis.

If the findings of one LCA are to be related to another, individual sources of pollution have to be compared and weighted. Weighting depends, however, to a considerable extent on the current world view. In the 1970s, for instance, energy consumption played a vital part in the assessment of environmental impacts; in the 1980s, the pollutants responsible for the death of forests became the most important criterion; in the 1990s, CO_2 emissions and global warming have become the number one topic.

Questions arise about the extent to which any assessment should look upstream of the process. Production of natural feedstocks may give rise to unsuspected problems at the "cradle" stage, as in the case of the production of biodiesel from oilseed rape where very large-scale cultivation raises two potential upstream problems: widespread pollen allergenicity and possible soil impoverishment following prolonged cropping.

LCA does not consider economic factors, but this is an issue requiring further consideration. It is argued that because of its quantitative nature, LCA may enable a trade-off between environmental impact and other elements, including cost components. Moreover, it is possible to equate clean technology with reduced risk as well as resource efficiency and waste minimisation. To what extent, then, should risk assessment be incorporated into LCA?

Examples of biotechnology-related LCAs can be found in the areas of cleansers and detergents, where assessments have been used for individual substances, such as enzymes, in waste technologies and in the renewable raw materials sectors.

For biotechnological processes or products, reliable published data are even rarer than for chemical processes, and comparisons of the two processes are the exception rather than the rule, for two main reasons. The first is the relatively recent appearance of biotechnological processes, and the second is the greater methodological difficulty involved in assessing biotechnological processes. Decision rules for defining system boundaries are needed for forestry processes, for example, which may be considered as part either of the environment or of the economy. Which activities and processes are to be considered part of the production system and which are part of the environment? Moreover, the baseline data for biotechnological production are often inadequate. Access to vital information may be withheld by companies on the grounds of confidentiality and company strategy. Nonetheless, examples from different industrial sectors seem to confirm the environmental advantages of the biotechnological alternative.

Example 1. Enzymatic versus chemical clean-up processes

Novo Nordisk A/S have a process for removing residual hydrogen peroxide after bleaching prior to dyeing. This step is called bleach clean-up and uses the enzyme catalase. Its advantages are there are no adverse effects on dyestuffs, no need to heat or rinse prior to dyeing, no risk of harmful overdosing and no formation of by-products in wastewater. Also, catalase is biodegradable and not toxic for aquatic organisms. The company has published the data from a comparison between three different methods of bleach clean-up – cold rinsing, use of reducing agents and use of catalase. By using the enzyme, the dye-house saves up to 19 000 litres of water per tonne of textiles and by substituting the enzyme for a reducing agent in a hot rinse, additional savings of 1 600-1 800 megajoules/tonne of textiles can be made. Because of the reduced energy consumption, release of CO_2 is lowered by 100-120 kg/tonne of textiles produced.

Example 2. Stonewashing of jeans

Jeans are one of the world's most popular clothing items. The "stonewashed look" has traditionally been achieved by removing the indigo dye through a process in which pumice stone is added to the washing drum to abrade the garment. Enzymes can be used to facilitate the removal of the indigo from the yarn surface. In practice, there are three washing methods: stone washing with pumice alone, stone-free washing with enzymes alone ("biostoning") and washing with a combination of pumice and enzymes. Today, biostoning is the main process used in the denim finishing industry, a shift promoted by process economics, fashion and, to a lesser extent, environmental concerns.

An LCA was performed on the three methods for reducing the indigo content. There are three specific process steps in producing stonewashed jeans, namely: stonewashing, wash off (removal of the stones), and wash (clean-up of the garment). The LCA covered only these three steps. The system boundaries included the mining of the pumice, the production of the cellulases, transport, and finally the jeans finishing process.

The LCA results show that the biostoning washing method scored best on eight out of ten environmental parameters. The "combined" washing method scored best for water toxicity because the biostoning washing method resulted in higher emissions of phosphorus compounds into water, and the pumice washing process was better under the heading "odour" mainly because of the ammonia emissions from agriculture from the production of ammonia for fertilisers used to produce the raw material for cellulase fermentation.

A cost comparison based on environmental regulations or needs was also made for the three methods. The highest costs are for wastewater treatment and were highest for the pumice method and lowest for biostoning. Cost differentials will increase if potential future standards for sustainable development are to be met.

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Example 3. Gene technology to reduce environmental pollution

Proteases, which remove protein impurities, are essential components of modern detergents. Because of their catalytic effect, low concentrations (0.1-1.0%) are used. Similar washing performance cannot be achieved by substituting other substances or by raising the washing temperature.

An LCA was made to compare the production of proteases from a traditional micro-organism and one from a genetically modified organism in order to determine the level of pollution linked to enzyme production and to reveal any weaknesses in the production. The assessment did not cover the whole life cycle of detergent proteases but only enzyme production, including all processes from raw materials to the finished granulated product.

To produce a quantity of enzyme with an equivalent washing performance from the recombinant organism required 34% less raw material. The change from conventional production to production using the new organism reduced the demand for process energy by 60%. In terms of the manufacturer's total annual requirements, this energy saving corresponds to the annual primary energy consumption for laundry purposes of about 170 000 households. Application of the new enzyme produced with genetically modified organisms made it possible to reduce annual emissions by approximately 170 tonnes of carbon and 190 tonnes of sulphur dioxide. Atmospheric emissions were assessed in terms of their impact on global warming, development of acid rain, and smog formation. Aquatic emissions were assessed on the basis of the yield of nutrients in waters and related oxygen consumption. The assessment clearly confirms the claim that the use of the new organism reduced consumption of energy and resources as well as emissions by a factor of three to four.

Example 4. Bioethanol production

Ethanol can be produced both biotechnologically and synthetically. In 1991, worldwide annual production of ethanol was 15 million tonnes, of which over 12 million tonnes were produced from agricultural resources. In terms of volume, and excluding beverage production, ethanol is the most important biotechnological product. In financial terms, it is only exceeded by antibiotics production.

Bioethanol is made from the sugar in crops such as sugar cane, beet, or maize. When made from sugar cane, the cane is crushed and the sugar is extracted using water. The residue, known as bagasse, is used to generate steam for the subsequent processes. Yeast is used to ferment the sugar, and the ethanol is removed by distillation. Burning the bagasse for fuel means that the part of the ethanol production process from cane crushing to distillation is self-sufficient in energy. The waste from the distillation process is known as stillage and is used for fertiliser or animal feeds.

Ethanol production from renewable raw materials requires very large amounts of energy which are, however, predominantly renewable. The demand for fossil energy (6 megajoules/kg ethanol) is small and is needed for fertiliser, transportation and machinery. The energy demand for grain is lower, owing to the allocation of environmental pollution to associated products (*e.g.* animal feeds), but the production process relies on an external energy supply. For this reason, the amount of fossil energy required rises to about 19 megajoules/kg ethanol.

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Synthetic ethanol is produced from ethylene by catalytic hydration with sulphuric acid and the resulting ester is hydrolysed. Synthetic ethanol production uses crude oil and natural gas as the carbon source. The process steps – refinery, steam cracker for ethylene production and actual synthesis – consume 62 megajoules/kg ethanol of fossil energy.

In terms of CO_2 emissions, biotechnological production has major advantages: Bioethanol absorbs CO_2, more so in the case of sugar cane than of grain. In terms of other emissions into the air, the data are less reliable. For emissions such as sulphur dioxide, bioethanol and synthetic ethanol are in the same range. For particle emissions, sugar cane is at a disadvantage and both sugar cane and grain release more nitrogen oxide than the synthetic process.

V. RESEARCH DIRECTIONS FOR BIOTECHNOLOGY

The technical and economic hurdles to the more rapid penetration of biotechnology into industry present challenges to the R&D community. There is already a wide range of biotechnological processes which can be employed for industrial production, but much needs to be done in the way of applied research and demonstration projects in order to show that laboratory and small-scale R&D activities can be scaled up to industrial production levels. To what extent must further fundamental research be performed, and if it is generic research, how should it be funded? Since development is industry-specific, company-specific and even process-specific, industry must play a direct role.

Among the technical impediments to the further penetration of biotechnological processes are the hydrophilic nature of biocatalysts and their inactivation at high temperatures. In addition to requiring high levels of water use, these processes may also require complex process equipment. Yields may be low, owing in part to incomplete understanding of metabolic pathways and physiological control mechanisms. For example, the production of biopolymers using microorganisms typically requires five times as much water to separate the biopolymer from the biocatalyst than is required for conventional chemical processes. This means more energy and much higher water processing capacity and an environmental impact that goes well beyond simple cost considerations.

Efforts under way in various research areas to find ways to overcome these obstacles include the search for new biocatalysts, for new enzymes, for new synthesis routes, for better reaction media, for making use of advances in recombinant DNA technology, as well as protein engineering, metabolic pathway engineering, directed evolution and bioinformatics.

Novel biocatalysts

The search for novel biocatalysts takes two directions: *i*) searching in natural habitats, such as geothermal sites, for biocatalysts that can function at high temperatures and in artificial environments; *ii*) modification of existing biocatalysts by genetic or physico-chemical methods. Developments in molecular biology are facilitating the exploration of the microbial world and helping to capitalise on its genetic potential. Gene probes are being used to identify micro-organisms with specific biocatalytic properties which can be detected even before they are culturable. Genome studies are also revealing the sequences of genes and their functions and are throwing up novel enzymatic capabilities.

Because biological catalysts as a class are not very stable, this poses a major problem for their industrial use. In nature, enzymes are replaced when they wear out in living cells, but in a chemical plant replacement is time-consuming and costly. Altus Biologics, a subsidiary of Vertex, has commercialised cross-linked enzyme crystals (CLEC®). Many enzymes can be crystallised, so that enzyme molecules occupy repeating points in a regular three-dimensional array. In this array, individual enzyme molecules retain their activity and that activity is often hundreds of times more stable than that of the same enzyme in solution. Although CLECs can still be improved (enzyme molecules in the centre of the crystal do not have access to substrates, for example) the marketplace has accepted these products.

Extremophiles are organisms with unusual biochemistries which are being collected from the very harshest environments on Earth: the depths of oil wells, arctic ice, desiccating salt marshes, and above steaming heat vents under the ocean. Extremozymes, the enzymes from these organisms, are more robust and operate at higher temperatures (but well below those of conventional petrochemical processes). Many groups are interested in the enzymes from these organisms because we do not yet have a catalyst which is as selective as an enzyme, and enzymes from ordinary micro-organisms are often too delicate for use in most industrial processes. For this reason, chemists are looking for "extremozymes" that combine exquisite precision with the toughness needed to survive in industrial processes. Ultimately, the hope is to outdo nature and make enzymes that can perform in environments that would be deadly to the hardiest of creatures. The rewards would be high, as the example of the commercial enzyme taq polymerase shows. This enzyme from a thermophilic bacterium is the basis of the polymerase chain reaction (PCR). It has revolutionised entire areas of biochemistry while resulting in hundreds of millions of dollars in sales. Yet taq polymerase is not considered a true extremozyme. Although it is hardy enough to survive the repeated heating and cooling steps of the standard PCR, it breaks down at the "cool" temperature of 80 °C. Researchers are experimenting with hardier enzymes from deep-sea vent bacteria, where pressure allows the water temperature to reach 120 °C.

Media

Enzymes do not need to be kept in an aqueous medium to catalyse technologically useful reactions, and this has led to a new form of biotechnology in which enzymes are controlled by water depletion and persuaded to form chemical bonds they would normally break. An interesting commercial use of low-water organic solvent enzymology has been developed by a DSM/Japanese joint venture to produce aspartame in the solvent ethyl acetate. This alternative to chemically synthesised aspartame is already marketed and is being produced on the multi-tonne scale. Another example involves enzyme-catalysed transesterification of monosaccharides with vinyl acrylate using pyridine as solvent. The resultant esters are isolated and subsequently polymerised to form materials capable of holding 50 times their weight of water. These polymers are largely biodegradable.

Attention has turned more recently to supercritical fluids (SCF) as media for biocatalytic reactions. These are non-aqueous materials held above their critical temperature so that they cannot be liquefied: they bridge the gap between the properties of liquids and gases. SCFs offer a number of major advantages for bioprocessing, including increased enzyme reaction rates, protection against microbial contamination and recycling options. Enzyme activity and substrate specificity can be manipulated by modifying the pressure under which the reaction is made. The enzyme lipase has also been used to catalyse polyester synthesis, and when the reaction is made in SCFs such as fluoroform the molecular weight of the polymer can be controlled by the reaction pressure.

Recombinant DNA technology

Recombinant DNA technology offers a very powerful means of combining diverse genetic capabilities. It permits the genetic engineering of organisms with specific catalytic capabilities, so that they can carry out specific catalytic activities and function at high temperatures, at high solvent concentrations, or in other conditions that characterise industrial processes. In many cases, enzymes from extremophiles can be transferred into more manageable organisms such as E. *coli* or yeasts that are traditionally cultured in industrial reactors. Conversely, catalytic capabilities of less tolerant organisms can be transferred to those that grow best under harsh environmental conditions.

Recombinant organisms can be used to produce enzymes that are useful biocatalysts. Since these recombinant organisms can be grown under contained good large-scale industrial practices, safety issues relating to environmental release are minimised. While there are advantages to the recombinant enzymes, some countries still require the use of the non-recombinants for certain applications, such as food production. However, use of modern biotechnology can have a favourable environmental impact when compared with traditional techniques. For example, enzymes derived from recombinant organisms have higher fermentation yields and therefore reduce the consumption of resources for their production.

Protein engineering

Protein engineering is beginning specifically to alter the amino acid sequence of enzyme proteins in such a way that their folded 3-D structure acquires more or less stability under industrial conditions, and/or confers an altered substrate preference closer to commercial needs. Developments such as these have been made possible by some remarkable discoveries about the behaviour of enzymes at the molecular level. An enzyme, xylose isomersase, is inactivated by a chemical reaction between glucose (its substrate) and the lysine units critical to its 3-D structure. Researchers at Gist-brocades have found a way to modify the gene for the enzyme so that the lysine units are replaced by others, which are less reactive but which will still hold the enzyme structure together.

Biochemists at the University of Colorado have designed and produced the first completely synthetic enzyme by creating a molecule that would mimic chymotrypsin. Using a computer programme that models the shapes of proteins, the team designed a molecule that would support the key amino acids in the right geometric positions. The investigators then synthesised the molecule which, although not as fast as the natural enzyme, is more resistant to high temperatures. They are also hoping to anchor artificial enzymes onto a solid matrix. If that effort is successful, artificial enzymes with such properties as superior temperature resistance might constitute a new generation of catalysts.

Bioconsortia and metabolic pathway engineering

In nature, micro-organisms rarely, if ever, live as single species. Instead, several species, each with different functions, act co-operatively. Traditionally, industrial microbiology has adopted the simple technique of working with a single species, but it is now understood that by copying nature and bringing selected species together, it is possible to perform reactions that would otherwise be difficult or impossible to carry out. A complementary strategy for bringing about unusual reactions is known as pathway engineering. It involves the assembly, via recombinant DNA technology, of metabolic sequences in a single organism (*i.e.* ascorbic acid and 1,3-propanediol). Early targets were the design of micro-organisms to effect the degradation of toxic chemicals that are difficult to degrade, such as polychlorinated biphenyls and dioxins. Recently, the technique has been successfully employed for the first time to evolve a metabolic pathway *in vitro*, namely a three-gene combination coding for the resistance to arsenic. Research is also progressing on the development of so-called "one-pot" multi-enzyme reactors, where mixtures of enzymes are used in cell-free systems to achieve complex syntheses.

Directed molecular evolution

A recently designed strategy in which the properties of natural enzymes or proteins are modified in order to create desirable properties has become known as "directed molecular evolution". A complementary approach is the technique of "DNA shuffling", which involves taking a set of closely related DNA sequences, fragmenting them randomly, and reassembling the fragments into genes. This process rapidly produces a combination of positive (desired) variants as the output of one cycle becomes the input for the next cycle, so that reiterative DNA shuffling leads to effective directed molecular evolution. A great advantage of these procedures is that they can be applied to evolve any protein rapidly even if the structure is unknown.

Chemical engineers who try to design real industrial processes using biological catalysts are constantly stymied by a simple fact: biological systems have evolved over billions of years to perform very specific reactions within particular environments. Some of these features are undesirable when the catalyst is removed from its natural context. Conversely, many of the properties that are desirable in an enzyme clash with those desired for industrial processes. Recently, directed molecular evolution has emerged as a powerful alternative to rational protein engineering for developing novel enzymes.

By building enzymes with new features and functions, enzymes can be tuned to function optimally under specified conditions. Directed molecular evolution can be applied even when very little is known about an enzyme's structure or catalytic mechanism. Since the vast majority of proteins remain largely uncharacterised, this is a huge advantage. The process has been used to effect improvements in, for example, enzyme stability in organic media and substrate specificity. The protease enzyme subtilisin, which is used as a laundry aid, is stabilised by calcium. Unfortunately, industrial use of this enzyme frequently occurs in the presence of chemicals that bind calcium and consequently destabilise the enzyme. The part of the enzyme that binds calcium can be deleted, and directed molecular evolution can then be used to develop subtilisin stability that is independent of calcium. An evolved enzyme has been produced that retains the native catalytic activity but has a 1 000-fold increased stability under strong metal-binding conditions.

DNA shuffling can also be applied to subtilisin. Directed evolution of the enzyme, for example, has produced variants with either improved stability towards hydrogen peroxide or with enhanced activity, but they rarely show improvements in both properties. However, the two variant populations can be recombined by shuffling to create enzymes that are more stable and more catalytically active.

Bioinformatics

Bioinformatics is a new field, based in computer science, mathematics, computer and software engineering and biology. It is concerned with the assembly, storage, retrieval and analysis of computer-stored databases, including databases of DNA and protein sequences and phenotypic information. A subset of bioinformatics is called genomics, the goal of which is to obtain gene maps and the complete DNA sequences of organisms. The first sequences were achieved in 1995 for two bacterial species, four more were announced in 1996, and by the end of the century, tens of sequences are expected to be available. In addition, mapping and sequence analysis of various animal and plant species are also proceeding rapidly, particularly for the human genome. Data from genomic analyses can be used to address a variety of questions, especially the biotechnological exploitation of novel organisms such as extremophiles.

VI. THE ROAD TO SUCCESS

Biotechnology can be the basis for a radically new approach to sustainable development. At its core is the principle of working in harmony, rather than in conflict, with the natural world. Biotechnological solutions can supplant existing technologies that pollute the biosphere and/or deplete finite resources. A strategy that reduces the impact of such technologies clearly improves, rather than degrades, the quality of the natural environment. However, the major stakeholders – industry, government, the research community and not least the public – need to act in concert if biotechnology is to fulfil its promise as a contributor to industrial sustainability. All the evidence shows that collaboration between stakeholders is essential.

The main drivers for industrial biotechnological processes are market forces, government policy and science and technology. Their relative importance varies from sector to sector. Market forces respond to the profitability of incorporating clean technologies, government policy reflects public interest in a cleaner environment and science and technology provide methodologies and establish technical feasibility.

The public's view

As with any other technology, perceptions of biotechnology are influenced (sometimes very strongly) by information disseminated through the media and other channels. Keeping the public informed is thus of crucial importance to the complex links between technology, regulation, political action and public endorsement or rejection of new technical developments.

Very few surveys have specifically explored public views on the environmental aspects of biotechnology. In a study conducted in Canada in 1996, which focused exclusively on environmental applications, participants were generally supportive, particularly when links were made to familiar technologies, *e.g.* composting and production of biofuels. Participants also endorsed biotechnology applications when they were kept informed of the benefits and risks. Environment and health applications of biotechnology were considered a higher priority than food production.

There is considerable scope for initiatives to promote wider awareness of the diversity of microbial activity. Two projects that already do so are the Microcosmos Science Education Museum at Boston University and the American Society for Microbiology's Microbial Literacy Collaborative, based in Washington, DC. Travelling exhibits, workshops and science fairs can foster greater awareness of the positive roles of micro-organisms. A specific issue that needs to be addressed is that of the many positive roles that micro-organisms play in the natural world. Micro-organisms are commonly perceived as agents of disease, while the far greater populations of beneficial microbes, which are essential to life on Earth, are neglected. Wider recognition of the vast amount of microbial activity beneficial to the environment and human society is likely to encourage support for the harnessing of biological agents in fields such as clean industrial technologies.

Biotechnology applied to the development of environmentally friendly industrial processes could appeal to young people, who are strongly motivated by concern both for the environment and for the less privileged regions of the world. School curricula now incorporate topics such as recycling and renewable energy, which may be deepened and extended to include the concepts of global stewardship and environmental citizenship. Environmental studies are quickly becoming a part of liberal and scientific university curricula. Schools are very appropriate communities in which to develop the idea of sustainable development. Long-standing attitudes and opinions are often formed in the classroom, especially when endorsed by a respected teacher.

In the higher education sector, the principal need is to broaden the training of scientists, engineers and technical managers. Concepts such as life cycle analysis and environmental sustainability need to be thoroughly integrated into their education and thus their future thinking. A chemical engineer engaged in developing new processes has not previously had to consider the environmental impact of obtaining raw materials, nor even, in some instances, ways of disposing of by-products.

Helping to educate the next generation of environmental scientists and engineers is an objective of a scheme launched by the US National Science Foundation and the Lucent Technologies Foundation in 1997. Researchers across the country have received grants intended to advance industrial ecology and to encourage businesses to integrate pollution prevention into their day-to-day operations. Each grant will support an individual or team involved in research or teaching to help industry design processes that prevent pollution and create environmentally friendly products.

Pre-eminent among target audiences are opinion leaders (including editors of major newspapers, magazines and radio and television programmes), non-technical staff in the biotechnology and other industries and politicians. There is a particularly keen need for greater mutual understanding and co-operation between business leaders and environmentalists. If the transition to a new generation of environmentally benign technologies is to be achieved, they will have to agree on a common agenda.

What can government do?

Government policy is a major force behind cleaner technologies, and in many cases and countries, the single most decisive factor in their development and diffusion. Policies that involve the general public have the most far-reaching effects. As consumers' lifestyles change and the demand for cleaner products becomes the norm, policy will follow the wishes of the public and become an economic instrument driving changes in manufacturing procedures. In the public arena, easily accessible formal and outreach educational programmes are needed to inform the public about biotechnology and clean industrial practices.

However, regulations governing biotechnology must be dynamic and responsive enough to account for the fact that science and technology are constantly evolving. Harmonisation of the principles underlying government oversight, particularly with respect to industrial uses of recombinant biocatalysts, is crucial to removing obstacles to the wider industrial penetration of clean biotechnological processes.

Government can also play an economic role by helping biotechnology over the initial barriers to acceptance by giving new technology a selective advantage via the tax system. It can also play a regulatory role, by obliging industry to adopt cleaner technology for the wider environmental benefit, regardless of the increased initial cost. It is important for government to recognise that for many individuals, the main issue will not be knowledge or technical understanding but rather confidence in the regulatory system, as it is for the safety of air travel, for example. Indeed, public trust is never likely to be secured by the provision of information alone. Equally important are factors such as the transparency of decision making about new technology, the assessment of risk, and the regulation and monitoring of research.

Finally, government can play a catalytic role by demonstrating and promoting the utility of biotechnology. Partnerships are necessary that integrate government, industrial and public roles to achieve industrial sustainability and utilisation of biotechnology.

Industry helping itself

In most cases, clean technologies are specific to a given process and even to a type of process within a single company. Companies decide to replace end-of-pipe technologies and adopt clean technologies when new production processes reduce costs in comparison to the previous production system or result in better process performance or product quality.

The transition to cleaner industrial manufacturing does not necessarily require completely new and costly plant and equipment; often, the introduction of biotechnological stages will achieve the desired result or existing plant can be modified. However, a bridge is required from basic research to final implementation, and this bridge can best be provided by partnerships between government, academia and industry that demonstrate applicability.

The private sector will rarely make the investments necessary to develop and incorporate biotechnological processes into existing systems unless their benefits are proven. This is especially true when profit margins are uncertain and not readily quantifiable relative to conventional technologies. Biotechnology has proved its worth for high-value speciality chemical production; its economic competitiveness for the production of commodity chemicals has also been demonstrated.

Companies consider the advantages of clean products and processes in terms of market niches and/or cost differentiation. Depending on their place in the market and their technological innovation, companies will make strategic choices about developing clean technology for offensive or defensive reasons. Industrial decision makers should note, however, that although the public will support government policies that encourage clean industrial processes and products, customers are reluctant to pay for the added costs due to clean production processes unless they see a direct benefit to themselves. It may not be easy to determine some of the economic benefits deriving from the adoption of clean processing, because it is difficult, for example, to weigh the costs of adoption against the probability of risk, *e.g.* avoidance of litigation costs where hazardous materials or practices are involved.

Industry needs to ensure that it operates within legal limits in order to minimise both liabilities and changes in operating practices. Establishing environmental legitimacy may take on strategic importance for industry, and many companies now make considerable efforts to assess their own activities from a broad environmental perspective and take initiatives accordingly. For many companies, environmental reporting has become a regular practice in response to shareholder demand and public expectations (Box 2).

Box 2. **One company's approach to environmental reporting**

In 1974, when Denmark's first Environmental Protection Act came into effect, Novo Nordisk, a manufacturer of insulin and enzymes, created an independent environment department, to ensure that it conformed with official protocols. In the late l980s, however, the company increasingly recognised a need to maintain a dialogue with customers, neighbours, environmental organisations, students, investors, employees and other groups.

In the run-up to the 1996 Rio Summit, the International Chamber of Commerce (ICC) drew up a l6-point Business Charter for Sustainable Development and allowed companies to declare their willingness to register, control and report on their environmental performance to the public. Novo Nordisk signed the charter, and uses it as a guide for its environmental work and policy. The company has undertaken to communicate openly, both internally and externally, and publishes an annual E*nvironmental* R*eport* so that interested parties can follow the company's progress in environmental matters. Recent reports have presented detailed pictures of the consumption of resources and environmental impact of all Novo Nordisk's production plants worldwide and also the company's compliance with legislation around the world.

The E*nvironmental* R*eport* is important internally, as well as serving as a source of information for those outside the company. It motivates staff by highlighting environmental goals and the results of the work carried out, and helps identify new problem areas, thus serving as a catalyst for improvements in Novo Nordisk's environmental work. The company believes in the importance of face-to-face dialogue for discussing environmental issues, especially in complex areas such as biotechnology. Large numbers of schoolchildren and students visit the company, and its environmental staff appear regularly at conferences and on external courses.

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VERIFYING NEW ENVIRONMENTAL TECHNOLOGIES

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I. INTRODUCTION

A decade ago, environmental technology verification (ETV) programmes were unknown; five years ago, they were barely nascent. Today, the community concerned with environmental technology – regulators, firms in the environment industry and officials promoting technology development, among others – is wholeheartedly embracing environmental technology verification as a means to simultaneously promote technological innovation and environmental quality. Programmes proliferate: more than two dozen now exist in the United States – by far the most active context – but support continues to build in circumstances as different as the Philippines and Canada. This article describes ETV programmes in the United States and Canada and the lessons which have been learned from their implementation; it should be noted, however, that information and data on these programmes are current to year-end 1998 and may have changed in the past year.

"Environmental technology verification" refers to the set of public programmes whose common element is the assessment of new environmental technologies. *Verification* – an objective determination of how a specified technology performs in specified dimensions – is by far the most common activity. *Certification* – another programme format – goes beyond verification to guarantee that a technology meets a particular standard of performance. This feature ties it more closely to regulatory compliance. *Technology evaluation* is broader still in that it attempts to judge the efficacy, cost or applicability of a technology for particular uses. *Demonstration projects* – which test technologies in actual conditions – typically combine verification and evaluation. Sometimes, programmes evaluate through comparisons among technologies, but this is rare.

The dramatic rise of environmental technology verification programmes in such a short period can be accounted for both by the popularity of the concept among a range of constituencies, and by the coincidence of two important trends: first, a new policy focus, centred on technological innovation in industry, that pervades environmental and technology policy; and second, a new receptivity to government-industry co-operation among regulators, regulated firms, vendors of environmental technology and entrepreneurs. Four particular aspects of the new context deserve mention.

Looking first to industry, one sees a transformed environmental goods and services sector that is mature, global and in flux (OECD, 1999). While annual sales top USD 450 billion, growth has slowed significantly in major markets, and competition has become much more intense. Only Asia, Latin America and Africa project new demand in double digits and, in the United States, sales growth is expected to be less than 1% (USDOC, 1997). Qualitatively, too, the traditional orientation – provision of pollution-control technologies – has broadened considerably into new approaches: analytical and consulting services, monitoring technology, intelligent process control, pollution prevention and "green design" among them (OECD, 1996). The industry encompasses a remarkable range of firms – more than 110 000 revenue-generating enterprises in the United States alone – and new national entrants – including emerging economies such as Korea – are being added to the mix.

The amassed technical capability in this technology-vending industry is enormous, and the industry as a whole naturally seeks ways to facilitate the commercialisation of the new technologies it produces. Technology verification programmes offer one important pathway. The need is perhaps felt most strongly by the most entrepreneurial and innovative segments of the industry (often small or new firms), where objective verification of performance to clients can make the difference between market success and failure.

Secondly, the client base for environmental goods and services has changed in a way which makes technology verification appealing. In the United States, Europe and Japan, leading firms routinely espouse their environmental management practices. Analytical techniques such as environmental auditing and industrial ecology have convinced many that environmental investments can co-optimise economic and environmental objectives. Receptivity to new technology is high. The barrier, however, is a double wariness: first, that an unproved technology may not work as promised, and second, that regulators may not accept it. In developing country markets or in the case of less technically sophisticated firms, the lack of knowledge about better technology – which verification counteracts – is likely to be an even more significant barrier.

A third explanatory factor resides in changes in environmental and regulatory policy. From an apparent negative bias towards new technology in its early manifestation, environmental policy has now evolved to view technological innovation as an important avenue to improved environmental quality. One symptom of the transformed policy environment is seen in the worldwide impetus towards regulatory reform. Another is the proliferation of technology support initiatives – research and development, technical assistance, public/private partnerships, as well as technology verification – that have fast become a new environmental policy mission.

Lastly, the traditional tools of technology policy are being increasingly turned towards environmental objectives. Public research and development portfolios are shifting toward environmental technologies, particularly in the European

Community and Japan. In the United States, the Clinton Administration made an Environmental Technology Initiative (ETI) a major part of its technology policy almost immediately after gaining office (Heaton and Banks, 1998). Demonstrations of environmental technology are now a major programme item in ministries such as the US Department of Defense.

In this policy and industrial climate, environmental technology verification programmes enjoy much support and suffer few detractors. Undoubtedly, they serve a need, fit well into a newly emerging policy mix and have substantial appeal. At the same time, however, one can hardly doubt that the current enthusiasm is in significant part due to the fact that the programmes are new, that they are typically in a promotional rather than an implementation stage, and that their value is as yet unproved.

II. PROGRAMME DESIGN ELEMENTS

Although all environmental technology verification programmes share the common aspect of assessing new environmental technologies, the component elements differ widely. Any programme is thus presented with design choices that lead to variable outcomes. The discussion below outlines seven major design choices that face such programmes and suggests the trade-offs they imply: *i*) scope, *ii*) technologies, *iii*) data, *iv*) costs, *v*) participants, *vi*) linkages and *vii*) reciprocity.

Scope

Environmental technology verification programmes can be categorised as verification, certification or evaluation (defined above), according to the main function they perform. The choice of functional category tends to be determined both by value judgements about the appropriate role of government in the market-place and by practical considerations.

Programmes whose main function is technology verification are the most numerous. By and large, they see themselves as performing an informational function that will "make the market work" rather than an evaluative role for the private sector. Verification programmes thus place a great deal of emphasis on the generation of "good", "objective", and "quantitative" data. They are careful to distinguish clearly between their own function – verification of technology performance – and regulatory acceptance of its compliance with environmental standards. The tendency is for verification programmes to operate largely in the technical realm. Given this tendency, verification programmes probably can most easily implement and profit from cross-programme reciprocity.

Certification programmes – which guarantee performance characteristics – are generally linked closely to regulatory compliance and the achievement of environmental goals. This endorsement provides perhaps the strongest boost an environmental technology can achieve – which makes certification particularly attractive to technology vendors. On the other hand, since legal consequences are associated with it, certification needs to rest on highly certain evidence, and this can make programmes reluctant to certify broad claims. Certification may thus be a more costly, less flexible instrument than verification, although it is certainly a stronger marketing tool for the firms whose technologies receive this designation.

Evaluation-oriented programmes offer the most judgemental reviews of technologies. Often, evaluations encompass verification, real-life demonstrations, cost evaluations, problem assessment and cross-technology comparisons. Programmes where verification and evaluation mix may well be trying to choose technologies (often for government use) rather than simply offering information to the market.

Technologies

All environmental technology verification programmes must decide how broadly to cast the net of technologies whose performance they will assess. In this regard, one element of consensus, among even the broadest programme formulations, is to limit consideration to explicitly "environmental" technology. This is generally taken to mean technologies intended primarily for environmental improvement purposes, not those with incidental (even substantial) environmental benefits. Beyond this, most programmes focus on hardware – "equipment or equipment-based technologies" – thus excluding most analytical, accounting or consulting services. Many programmes have chosen to focus on a particular medium or problem – *e.g.* hazardous waste remediation, drinking water, air pollution – thereby narrowing the range of technologies and constituencies they reach.

Because environmental technologies differ so widely, schemes that distinguish among categories of technology are used routinely to ensure meaningful verification measures. The degree of formalisation in this dimension differs widely, with some programmes pre-establishing a list of categories and attendant test procedures, and others taking a flexible stance, matching verification data with technologies as appropriate. Both approaches have pluses and minuses: while flexibility can require frequent, costly new approaches and unsystematic data, precategorisation runs the risk of imposing an overly rigid classification of technology on a dynamic industry.

Data

Since good data are central to their success, all environmental technology verification programmes must come to terms with how they acquire, handle and interpret data. One of the most important choices in this regard is whether to accept outside data as a basis for verification or whether to generate data exclusively within the programme. Outside data generally come from two sources: the applicant's own claims and tests, and other test facilities (often commissioned by the applicant). Data generated by verification programmes often come from public labs or universities commissioned by the programme. Frequently, the issue is formed in terms of whether the data for decision making is "independent and objective". Some programmes are strongly insistent on independent data, even enough to expend programme funds to obtain it. Others accept data commissioned by the proponent of the technology, so long as it was developed by an independent entity. Others still will accept any data – even applicant claims – as useful input to the verification process.

A similar issue concerns how to make verification assessments. Some programmes establish *a priori* test protocols, to which applicant technologies must be submitted. Development of these test protocols can itself become a time-consuming and contentious issue, since it has the effect of excluding technologies that cannot satisfy the particular test protocol chosen. Other programmes eschew protocols, verifying with whatever means seem appropriate to the circumstance.

In both instances, the choice of how formal and rigorous to make verification activities reflects a judgement about the trade-off between how "good" (in a technical sense) the data are, how relevant they may be to users' and vendors' needs, and how much to spend on data acquisition. Particularly where technology developers' claims and tests are used as part of the verification database, the issue of confidentiality and proprietary rights arises. Programmes that accept such data may often agree to applicants' claims of confidentiality. In contrast, those that rely on independent sources of data usually insist on openness.

Costs

Like all public programmes, environmental technology verification initiatives face the need to establish an appropriate level of cost. Beyond the size and comprehensiveness of environmental technology verification activities – obviously the largest driver of cost – the question of cost-sharing will determine where cost burdens are placed. This, in turn, affects the numbers and types of applicants involved in the overall programme.

There seems to be a clear consensus in US programmes that the firms applying for technology verification should bear its cost. In some states – *e.g.* California – this is already the case. In the programme of the US Environmental Protection Agency (USEPA), the intention is for the programme to be basically self-sufficient after the pilot phase. The cost-sharing feature has the clear advantage of creating a salutary incentive structure: firms with promising technologies are more likely to go forward than those of lesser promise. On the other hand, the need to bear the costs of verification may present a significant hurdle to firms with promising technologies but few resources. This is all the more likely to occur when the only acceptable data come from independent test entities. As in other situations in which the industrial community bears the cost of testing (*e.g.* pharmaceuticals, chemicals, pesticides), cost-sharing may create a bias in favour of larger firms with ample financial and technical resources to carry these costs. This bias can be balanced by policies that take a flexible approach toward the cost-sharing decision, particularly for smaller firms.

Participants

Public programmes throughout the environmental and technology arenas now routinely solicit the involvement of non-governmental institutions and individuals. Being both responsive to industry needs and highly dependent on technical expertise, technology verification programmes strongly exhibit this external orientation. Perhaps the most formalised attempt to recruit external participants is the "stakeholder" process of the USEPA programme. This programme involves industrial firms, trade and professional associations, universities, and governments in a co-operative enterprise to advise, among other issues, on programme priorities and test protocols for each of the technical areas in which verification occurs. In addition, EPA's current pilot programmes are all being run as "partnerships" among private and public entities. Canada's experience demonstrates the degree to which verification programme implementation can be almost entirely externalised. Strongly advised from the beginning by industry, Canada chose to establish its verification entity, Environmental Technology Verification Canada Inc., as a private company with a mixed ownership rather than as a governmental organisation.

External participation has many benefits: decisions are generally better informed, supportive constituencies are created, costs are kept down. On the other hand, it must be recognised that the players who combine the largest stake in the outcome with the largest available resources are typically the dominant sources of external participation. In environmental technology verification programmes, these will tend to be technology vendors. To the extent that their presence is not balanced by other views – particularly competing views of the types of technology that need to be verified – the verification system can become biased.

Linkages

Although environmental technology verification programmes could relate naturally to both environmental and technology support programmes, few do so. Most are housed, administratively, in either environmental or technology programmes, and this tends to define their orientation. For the environmental technology verification programmes housed in environmental agencies, the choice quickly arises of how co-ordinated they should be with the regulatory compliance apparatus. Some programmes take the position that they are purely "informational", and that their verifications do not in any sense imply regulatory approval. On the other hand, others explicitly try to feed information to regulatory officials so as to promote better compliance policies generally and open the door to specific new technologies. Other environmental technology verification programmes have been developed as components of technology promotional efforts (particularly among US states), which include venture capital, technical assistance, marketing help, etc., for fledgling firms. In these instances, the environmental technology verification activity may be seen mainly as a service to innovators, with the environmental consequence a secondary concern.

Reciprocity

The rapid proliferation of environmental technology verification programmes within the United States and worldwide raises the possibility of national programmes imposing widely differing standards and procedures, thus confronting environmental innovators with the need to verify their technologies repeatedly. Although no one wants this scenario to materialise, programmes tend naturally to be protective of their own standards, which they feel have been developed to suit their unique situations. Design choices about whether and how to co-ordinate, harmonise, or share reciprocally with other programmes are now becoming pressing issues. The possibility of internationally harmonised environmental technology verification standards is beginning to be discussed as an attractive possibility called for by an increasingly global supply and demand for environmental technology. Although some reciprocity has begun among US state programmes, and a number of co-operative statements have been signed, the issue of reciprocity and/or harmonisation will remain the subject of much more attention before any resolution is reached.

III. PROGRAMME EVALUATION

For such a new programme concept, environmental technology verification is a surprisingly well-studied phenomenon. As early as 1995, when most of the programmes were only just getting underway, a major survey by the US Environmental Law Institute reported on environmental technology verification "*stakeholders*", documenting their views of the effects of technology verification and how they thought the programmes should be structured (ELI, 1995). There have also been interview-based studies (Cooper and Susskind, 1997) and a major survey involving almost all the programmes now in existence (ITRC, 1998). Many of the environmental technology verification programmes track and publish their own outputs. The

USEPA programme, most notably, has conducted a pilot-phase self-evaluation. These yield the following general findings:

- *Extent*. Although no hard numbers have been tallied, a few hundred environmental technology verifications have probably been made over the past five years. This level is likely to continue and to increase.
- *Technology assessment*. Completed verifications undoubtedly increase the marketability of subject technologies, and certifications even more so. This is fairly widely reported. As to the "weeding out" effect for inferior technologies, the evidence is less clear. Since few if any applicants would attempt to push non-qualifying technologies through the verification process, there are virtually no negative results to examine. Presumably, however, the rigour and cost of verification does deter applicants with weak technical cases or limited resources from pursuing it.
- *Technology diffusion*. Information about environmental technologies is being distributed widely through the verification process. Virtually every programme has a Web site and most publish aggressively. Perhaps even more importantly, the applicants who receive certificates from the programmes are aggressively promoting the information themselves as a marketing tool.
- *Public/private partnerships*. It seems clear that verification has led to a newly co-operative, consultative relationship between government officials and private firms in the environmental arena. Programme advisory councils are the norm, enlisting academic and other experts as well as industry representatives. However, many verification programmes are promotional, looking to improve the competitiveness of their firms.
- *Costs*. Reported certification costs are unlikely to account for the additional costs spread through public entities, or the cost of time. Nor are they insignificant for small-market technologies, for small firms or if repeatedly incurred. Programme costs will also increase as a function of increased scientific rigour, data collection and procedural formality.
- *Regulatory compliance*. Since verification certainly does not imply regulatory acceptance, and even certification programmes can be poorly co-ordinated with regulatory compliance decisions, the proponents of new environmental technologies run the risk of finishing verification and being turned down or delayed further by sceptical regulators. Ironically, if regulators become more willing to accept new technology, the value of a verification process diminishes. Some environmental technology entrepreneurs, sensing this new possibility, do not see the verification route as necessarily the fastest or most cost-effective to regulatory compliance.
- *Innovation*. Verification programmes seem likely to speed the diffusion process for incremental improvements that are currently available, but may offer little support to more radical innovations. Indeed, some programmes

explicitly adopt screening criteria that exclude early-stage technologies – for the obvious reason that they are not yet reduced to verifiable practice. The technology categorisation schemes and attendant test protocols utilised by some verification programmes seem to have a variety of competing effects. For one, they are likely to discourage applicants whose approaches do not fit the categories. More specifically, since most verification categories tend to correspond to established elements of the pollution-control industry, they are most attractive to these technology vendors rather than to new entrants. Nevertheless, when the categories of verification are narrowly drawn – *e.g.* air pollution monitoring – and the proliferation of technologies within the category is high, verification can perform a major service in clarifying the market. On the other hand, the more open-ended technology strategies developed in-house by polluters rather than externally by vendors – pollution prevention being the leading example – are reported to be largely unrepresented in verification applications.

From a reasonable degree of evidence, it appears clear that environmental technology verification programmes generate a number of positive impacts: new technologies made more acceptable to purchasers and regulators, useful assistance to technology vendors, better dissemination of environmental technology information, and a co-operative decision-making process that links governments, private firms and the research community. However, there are also the risks of the imposition of a static categorisation scheme on the potentially dynamic environmental technology market and bias against small-scale entrepreneurs. In general, the technologies they verify seem mostly to be incremental improvements to pollution control, monitoring and remediation. Pollution prevention and other process and design changes interior to polluting firms seem in short supply. However, in the unfolding connection between new technology and environmental sustainability – as well as between environmental and technology policy – environmental technology verification programmes assume a valuable place among other initiatives.

IV. PROGRAMME RECIPROCITY

Environmental technology verification programmes proliferate worldwide. Their operating procedures, though still new and reasonably flexible, are beginning to solidify. To a greater extent than many would like, they are developing independently – both from analogous programmes in other jurisdictions and from other programmes and policies in the parent agencies where they are housed. Given these circumstances, a scenario can be envisioned where many programmes exist, each with different procedures, lacking reciprocity, whose inconsistencies impede rather than facilitate the very flow of environmental innovation they seek to encourage.

In an alternative scenario, programme managers and industry representatives anticipate and forestall impending problems. Indeed, there is some movement in this direction already in the United States, where at least 25 states have technology verification programmes. The obvious desirability of sharing information and avoiding duplication and/or conflicting standards among them has brought these 25 states, plus three Federal agencies (Environmental Protection Agency, Department of Energy and Department of Defense) together in the *Interstate Technology and Regulatory Working Group* (ITRC, 1998). ITRC's primary goal is to work for environmental testing and permitting results that can be accepted throughout its membership. The main means of working toward this end is the production of technical guidance documents, of which 22 have been developed by ITRC committees to date. More broadly still, the ITRC is compiling a catalogue of technology verification programmes and commencing an evaluation of 12 programmes. Clearly, the objective in mind is to promote consistency among the programmes, as well as sharing of information.

A further step in the process towards cross-jurisdiction consistency is contained in a Memorandum of Understanding (MOU) among six state programmes: California, Illinois, Massachusetts, New Jersey, New York and Pennsylvania. This document commits the states to defining a process for reciprocal evaluation, acceptance and approval of environmental technologies. Since the MOU goes beyond reciprocity in technology evaluation into actual regulatory acceptance, the process of moving it forward has not been easy or quick. On the other hand, as the agreement does commit a large part of the US environmental market to technology co-operation, it could mature into a mechanism of significant force.

Another force pushing towards greater programme harmonisation is the USEPA pilot programme, in which a wide variety of institutions and jurisdictions have been enlisted in crafting a comprehensive verification programme. However, there are counter-tendencies: certification programmes, such as in California, present an approach which is different enough to make increasing programme compatibility difficult, and certain newer verification programmes seem to be getting more specialised. In many parts of the world, interest in environmental technology verification is building.

From the vantage point of the global environmental goods and services industry, a worldwide proliferation of inconsistent environmental technology verification programmes can only represent a barrier to market growth and the free flow of its goods and services. Any attempt to increase the international compatibility of environmental technology verification programmes should address the major design features previously enumerated:

– *Scope*: how to define, co-ordinate or unify the different functions, particularly verification and certification, that programmes now undertake.

– *Technologies*: whether and what categories of environmental and other technology should be established.
– *Data*: what kinds of data should be accepted, test protocols and facilities established, and how should applicant claims and confidentiality be treated.
– *Costs*: to what extent applicants should bear costs and special provisions should be made for smaller firms.
– *Reciprocity*: how to provide for reciprocity or mutual acceptance of test results and data across programmes.

V. MAJOR PROGRAMMES

United States

Environmental Protection Agency

The USEPA environmental technology verification programme is certainly the largest and most comprehensive verification programme today. It traces its origin to wide-ranging proposals advanced early in the first Clinton Administration to support environmental technology and the US environment industry. This Environmental Technology Initiative (ETI) incorporated environmental technology verification as one part of an ambitious package of commercialisation initiatives, R&D funding and regulatory reform. Today, environmental technology verification is the only functioning element.

The programme began early-stage activity in 1994 and was officially established in October 1995 by EPA as a "pilot programme" for the period 1995-2000. Today, the environmental technology verification programme has become well institutionalised in EPA as part of the Office of Research and Development. Its budget has been USD 10 million yearly for the last three years, but the long-term steady-state is projected to be USD 2 million yearly (reflecting private firms' absorption of testing costs). Given its "pilot" status, the environmental technology verification programme is obliged to report and make recommendations to the Congress at the end of this period for consideration of continued funding and other authority.

The pilot phase of the EPA environmental technology verification is intended to develop and evaluate procedures, organisational structures and management approaches so as to be able to have a clearly defined programme operational by the year 2001. More specifically, the programme is in fact undertaking 12 separate pilot projects, each involving a particular technology and a particular partner. The technologies are: Drinking water, Site characterisation and monitoring, Pollution prevention, Improved coatings, Advanced monitoring, Air pollution, Climate change, Wet weather flow, Source water protection, Metal finishing, and EvTEC, an independent entity that represents an open-ended category. The pilot partners include private labs, national labs, universities, foundations, states and others.

After the selection of the pilot partner by EPA in an open solicitation, a "Stakeholder Group" of approximately 25 participants is convened to advise the project. Participants represent the range of interests concerned with verification, including vendors and buyers of the technology, professional and trade associations, state and local governments, financiers, etc. They are expected to be involved in setting priorities and to function as a sounding board for major technical decisions.

The verification activity itself begins with definition of test protocols for how and what to verify. In this respect, the EPA programme differs significantly from others – *e.g.* California and Canada – which do not insist on protocols and will, instead, accept any available data as input. Another difference is that EPA funding currently covers most of the costs of testing during the pilot phase. This degree of control allows EPA to focus to a high degree on quality assurance, which is further enhanced by requirements for independent third parties to conduct the tests and for peer review of their output. In further contrast to other programmes – *e.g.* the Department of Energy and the Department of Defense – EPA's verification activities do not include demonstration in on-site conditions. Though background data and published reports yielded about the technologies may be extensive, the actual Verification Statements are three-five pages in length. These are disseminated on the EPA ETV Web site and elsewhere as part of the programme's outreach effort.

EPA takes care to be clear about what its programme outputs are – and are not. Verification, thus, is simply a statement about how the technologies perform, and does not indicate approval by regulatory authorities or a certification or guarantee. Nor is it a comparison among technologies. The programme's goals are to provide information to the marketplace, facilitate technology acceptance, reduce risks to investors, level the playing field among competitors and facilitate US exports of environmental technologies. To date, more than 40 test protocols have been established and about a dozen verification statements issued. Monitoring technology is reported to be the most active area, and pollution-prevention technologies the least active.

While the EPA environmental technology verification is cognisant of the problem of standardisation – both within the United States and worldwide – the pilot phase has not concluded any formal arrangements to this effect. Indeed, even the other EPA programme with verification activities – SITE (discussed below) – is operated separately. Some state programmes are participating as EPA pilots, and discussions are underway internationally about the possibilities for co-ordination.

The EPA's Superfund Innovative Technology Evaluation (SITE) programme differs significantly from the environmental technology verification in that its technology verification efforts are only one part of a broader effort to develop and implement environmental technology. Moreover, SITE confines itself to a particular technological niche: treatments for hazardous waste site remediation and monitoring. SITE was instituted after the 1986 amendments to the US Superfund Act, which recognised a need for new remediation technologies at hazardous waste sites. Its method of operation is to first support research through co-operative agreements with technology developers, in which new technologies are refined at bench- or pilot-scale. Subsequently, EPA funds the cost of demonstration at hazardous waste sites. From such experiments, verification data are developed. All of these activities are administered through the Office of Research and Development's National Risk Management Research Laboratory.

In contrast to other verification activities, the SITE programme is concerned with broad evaluation of the technology according to a wide range of measures: capital investment, operating cost, range of applicability, operational problems, etc. It does not develop formal test protocols in advance, but issues evaluation reports after the demonstration which draw on all existing sources of information. These evaluations are distributed widely for use by parties involved in hazardous waste site remediation.

Department of Energy

The oldest US federal environmental technology verification programme was initiated by the Department of Energy (DOE) in 1993 (ITRC, 1998). DOE, long involved with nuclear technologies and their associated wastes, has been charged with very large-scale remediation efforts. These, of course, entail the expenditure of large sums of money for clean-up and give rise to the desire to employ the best, most cost-effective technologies. DOE's programme is called the Innovative Treatment Remediation Demonstration Programme (ITRD). It focuses on innovative technologies of promise that lack the cost and performance information that would otherwise permit their consideration as remedial alternatives in its own clean-up efforts. Soil and groundwater remediation technologies are those of most interest, particularly for small-scale (one-to-two acre) sites.

The DOE approach is different from other verification programmes in that it gathers data by demonstrating (*i.e.* actually using) the technologies in question in real-life conditions. The approach, common to demonstration programmes, is to gather verification data from one site, thereby making the case for implementation at other similar sites. A second major difference from the verification approach common in other programmes – where external sources typically undertake testing – is that DOE embarks on verification activities itself. These take place at many of its facilities throughout the United States, as well as in private or public/private partnerships (*e.g.* the Hemispheric Center for Environmental Technology undertaken by DOE and Florida International University). Publication of test results is an important aspect of the programme, designed to promote diffusion beyond the DOE context. The overall effort is co-ordinated by Sandia National Laboratories, one of the largest of the US national laboratories.

Department of Defense

The Department of Defense (DOD), like the DOE, has large-scale needs for clean-up, pollution-control and pollution-prevention technology to address environmental problems in its own facilities. To accelerate the acceptance of new technologies in this context, DOD established the Environmental Security Technology Certification Programme (ESTCP) in 1995. ESTCP, again like DOE's initiatives, is more a demonstration programme than a technology verification effort. Once technologies have been tried in particular sites, the results are published and efforts are made to transfer them to other uses through the well-established DOD technology transfer programme.

State programmes

Programmes in the US states present the most dynamic and diverse venue for environmental technology verification today. This is not surprising, given the fact that the US regulatory system relies heavily on state-level environmental permits, which in turn implies that much of the market for environmental technology – and much of the need for verification – is effectively made by regulators at the state level. California, Massachusetts and New Jersey are often cited as among the leading verification states.

California's programme can be seen as the prototype: it was the first to put the environmental technology verification concept into operation and pioneered many of its basic operating features. Over time and with programme proliferation, however, California's programme has come to depart from the norm in a number of respects, notably its choice of certification rather than verification.

The California programme originated in a 1993 recommendation from an advisory council to the California Environmental Technology Partnership. By 1994, a Hazardous Waste Environmental Technology Certification Programme had been approved by the legislature, which thus formed the core of the state programme. More recently, the Air Resources Board established a pre-certification programme (to co-ordinate with individual air districts that may establish their own programmes), the Water Board is setting up a programme, and the legislature has considered authorisation for all environmental agencies to develop their own certification programmes. California thus illustrates more than any other locale the popularity of environmental technology verification as well as its tendency to proliferate into many diverse individual programmes, each associated with a particular niche.

The certification process in California takes two different forms: regulatory certification, which is intended to streamline approval of the technology in the context of regulatory compliance; and performance certification, which is intended to provide an information and marketing device for technology developers both domestically and abroad, as well as an aid to regulatory decision making. In either case, the process is divided into three phases, which move from initial screening, through definition of what claims will be certified, to review of test results and/or testing. An important aspect of the California system is its willingness to accept tests results of virtually any type and from any source as input to the process. These data are reviewed by the relevant technical facility (*e.g.* the state Hazardous Materials Laboratory, selected university and national labs), which may choose to use them and/or conduct tests on its own. Whatever the case, the applicant for certification reimburses the state for the cost of the certification process, which in 1995 was reported to range from USD 3 000 to USD 60 000.

California's programme – being both first and technically robust – has been widely utilised. Hundreds of companies have approached the programme, and a few dozen hazardous waste technologies have been certified to date. No known technologies that went into the later stages of the process have been denied certification, but many have been weeded-out at an early stage. Other programmes rely on California expertise. This has prompted Memoranda of Understanding with Canada, the State of Bavaria, and five US states. California has also signed a co-operative agreement with the USEPA to participate in its pilot verification programme.

The one attempt at systematic evaluation (Cooper and Susskind, 1997) supports the view that California certification represents a major market plus for vendors who receive it, both in the United States and internationally. On the other hand, as the number of verification programmes proliferate – and particularly as they differ in format – it is not clear that the California approach will retain its impact. Going further, as the number of separate programmes in California itself proliferates, complaints are being voiced about the red tape involved and the need to make certification consistent with and useful to the regulatory authorities.

In M*assachusetts*, verification activities comprise one element of an overall promotional effort towards the state's environmental industry entitled the Strategic Envirotechnology Partnership (STEP), which was founded in 1994. More than 100 companies have been assisted in various ways by the programme. The verification component of STEP is carried out in a Technology Assessment Programme with two foci – environmental technology generally, and energy technology. Experts from the state University of Massachusetts review available data with respect to the technologies, but the final Technology Assessment Report is issued by panels which include business people and officials. The programme also attempts to tie its verifications to regulatory approvals to the extent possible.

The *New Jersey* verification programme, a relatively new programme, is of special interest because of its emergence from a larger technology promotion activity, the New Jersey Corporation for Advanced Technology (NJCAT). NJCAT is one of many technology promotion efforts at the state level targeting emerging technologies, but it is unusual in its focus on environmental issues, and its decision to mount a verification programme within this larger context. New Jersey is also noteworthy for the extent to which it has sought co-operation and reciprocity with other verification programmes, notably those in California and Canada.

Canada

Canada's programme became formalised in early 1996 as one outgrowth of a broad stakeholder and public policy consultation process that had proceeded over the previous two years. Its "Strategy for the Canadian Environmental Industry" originally recommended a certification programme but ultimately coalesced around verification. (The documents applicants receive are nevertheless verification "certificates".) Although Environment Canada, a government agency, is responsible for overall programme policy and direction, the effort is very much a public/private partnership: its Steering Committee has an industry majority, the Canadian Environment Industry Association provides regular input and evaluation in semi-annual performance reviews, and the administering entity, Environmental Technology Verification Canada Inc., is a private company built on public and private expertise.

Operationally, the programme verifies equipment or equipment-based services that "address an environmental problem or provide an environmental benefit", meet Canadian environmental standards, and are ready for commercial use. In recognition of the need to aid technologies in earlier stages, the programme also provides advice on testing and data generation to move such technologies towards the verification stage. Four stages move an applicant forwards from determination of eligibility to final outputs: verification certificate, environmental technology verification logo, fact sheet and final report. The applicant is entitled to use all of these in its efforts to market the technology.

Registered verification entities (VEs) process the applications but do not conduct on-site testing. Rather, most of the data is generated by applicants from tests commissioned at independent accredited testing facilities. This design feature is intended to keep costs down for the government and rely on applicants' incentives to produce data, while ensuring data quality and veracity. VEs evaluate the technology according to formal Verification Protocols. The choice of VE, as well as the determination of administrative issues such as data confidentiality, is made in consultation between Environment Canada and the applicant.

The economic benefits of verification have been particularly salient for the Canadian programme. "Reciprocity" and "a level playing field with other countries" are thus seen as key to the "competitiveness" of Canadian environmental companies. To this end, Canada has signed MOUs with the states of California and New Jersey. There is a co-operative agreement with the USEPA, as well as "further exploration of foreign markets" through contacts with the ISO, the UN Economic Commission for Europe and NAFTA's Commission for Environmental Co-operation. Although no formal output measures are yet available, the programme publishes a quarterly newsletter and is developing a CD-ROM technology database.

Other programmes

The Asian Pacific Economic Co-operation (APEC) region held an Environmental Technology Verification Workshop in Seattle, Washington, in September 1998 (PREC, 1998). The workshop was held under the auspices of the APEC Industrial Science and Technology Working Group, whose many projects revolve around the development of technology in the private sector. It received sponsorship and support from the USEPA and other public and private institutions in the Seattle area. The workshop enlisted representatives from 11 APEC countries, with the United States and the Philippines particularly strongly represented in terms of both numbers and presentations. The meeting's stated purposes were to identify needs and resources available among APEC members in the area of technology verification. This reinforced the momentum that is developing for ETV verification programmes at the member level; beyond this, the possibility of a verification consortium in APEC itself is being discussed.

The European Union does not have a formal ETV programme, but verification and certification of environmental technologies have been carried out as part of other activities such as eco-labelling and environmental auditing. The European Union has probably been most successful in integrating environmental programmes into its overall system of support for advanced technology, particularly in its later research plans (Heaton, 1997). Europe's lack of formal environmental technology verification may also be related to a regulatory process that is less formal and adversarial than that in the United States. However, there is significant discussion in Europe about specifying performance requirements for new environmental technologies.

Similarly, Japan does not have environmental technology verification programmes; this may be connected to the overall pattern of government-business relations, particularly as manifested in the administrative format of regulation. In

Japan, although the Environment Agency is instrumental in setting public-health-oriented, pollution-control standards, it is the Ministry of International Trade and Industry (MITI) that it responsible for standards implementation. MITI is known for its industrially oriented expertise, its sensitivity to the needs of industry and its consultative style, often termed "guidance". Given such conditions, the domestic regulatory process in Japan may be flexible enough not to need the kinds of formal verification programmes that other countries find attractive. In addition, because Japan does not have states or provinces like the United States or Canada, it is unlikely to suffer from the problem of inconsistent attitudes towards new technology across jurisdictions.

VI. CONCLUSIONS

Environmental technology verification refers to the set of public programmes whose common element is the assessment of new environmental technologies. These programmes have proliferated since the mid-1990s, particularly in the United States. By verifying performance, they facilitate market and regulatory acceptance of new environmental technologies, with the aim of promoting both innovation and environmental quality. The rise of such programmes is due to an increasing emphasis on the role of innovation in environmental policy, a growing consciousness of sustainable development objectives in technology policy, and a new receptivity to public/private partnerships and co-operation in regulation and compliance.

This review of environmental technology verification programmes concludes that programme design is important to increasing their efficiency and usefulness. Programme aims may be *verification* (of how a technology performs in a specified dimension), *certification* (of whether a technology meets a specific standard of performance) and/or *evaluation* (of the efficacy, cost or applicability of a technology for particular uses). Most programmes deal with equipment-based technologies (rather than environment-related services) and may focus on a particular medium (waste, water, air) and/or environmental problem (*e.g.* remediation). Programmes differ with regard to the test protocols and data they use and accept; the degree of cost-sharing between the public and private sectors; the involvement of external participants; their link to regulatory compliance procedures; and their reciprocity arrangements with other verification programmes.

Questions have been raised regarding the impacts of environmental technology verification programmes and their real contribution to innovation and environmental quality. The programmes have been documented to increase the marketability of the verified technologies, to promote technology diffusion through disseminating information, and to enhance co-operation between government officials and private firms in the environmental technology arena. However, it is not clear that verification programmes "weed-out" inferior technologies, promote real innovation or do more than speed the diffusion process for incremental technology advances. As the number of environmental technology verification programmes increases worldwide, there are also questions regarding the mutual acceptance of test data and verification results in the interest of promoting unfettered trade and technology diffusion.

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MAPPING THE ENVIRONMENTAL GOODS AND SERVICES INDUSTRY

Table of contents

This article was written by Graham Vickery and Maria Iarrera of the OECD's Directorate for Science, Technology and Industry. The work to prepare the manual was organised with Mr. A. Steurer of Eurostat.

I. INTRODUCTION

Globally, the environmental goods and services industry is growing rapidly in response to environmental pressures and the shift towards business and government strategies that are more sustainable over the long term. However, the industry which supplies the goods and services that enable businesses and nations to meet environmental challenges is poorly identified, measured and understood. In the context of globalisation, technological change and new political priorities, policy makers have expressed a strong interest in the environmental goods and services industry. This is widely seen as a new growth sector, which generates wealth and creates jobs as well as enabling the transition of economies towards sustainable development.

This policy interest has raised many questions on different aspects of the environment industry. These include: What is the potential for growth and employment creation? What is the record in exporting environmental technologies? Is there progress in research and development for cleaner products and processes? Can we measure the impact on industrial competitiveness due to the application of cleaner technologies? And how can environmental and economic policy be modified to encourage and support growth, job creation and trade in the environment industry? Answering these questions poses statistical and methodological difficulties related to problems of delimitation and data availability.

To begin to answer these questions, the OECD has been studying the evolution of the environmental goods and services industry since the early 1990s (OECD, 1992), with particular emphasis on the need for better classification and improved data on the industry (OECD, 1996*a*). A first meeting was organised in Washington in 1994, supported by the US Government, to help collect more comprehensive information to enable a clearer definition and classification of the environment industry, and provide a foundation for more firmly based policy analysis (OECD, 1996*b*).

As a follow-up, the OECD in collaboration with Eurostat (the Statistical Office of the European Communities) organised an I*nformal* W*orking* G*roup on the* E*nvironment* I*ndustry* to work towards better categorising the environmental goods and services industry. This group developed a common definition and classification of the environment industry to start to improve the collection of consistent information on variables such as production, employment, trade, investment and research and development (OECD, 1996*c*). This definition and classification was tested during 1996 and 1997 by collecting new data and re-organising available data in OECD countries. The results of this work were used to draft a manual under the joint aegis of the OECD and Eurostat which provides guidelines that can be used to produce comprehensive and comparable data on the environmental goods and services industry (OECD and Eurostat, 1999).

II. ROLE OF THE ENVIRONMENT INDUSTRY

The environmental goods and services industry contributes to environmental innovation and sustainable development as well as to enhanced performance and job creation at the firm level through developing more efficient and less resource-intensive products and processes. According to the European Commission, the development of a strong environmental goods and services industry can make a major contribution to enabling enterprises to better integrate cleaner technologies and environmental practices in production and more generally improve environmental and economic performance (CEC, 1997).

The environment industry comprises activities which produce goods and services to measure, prevent, limit, minimise or correct environmental damage to water, air and soil as well as problems related to waste, noise and ecosystems. The industry includes both end-of-pipe equipment and cleaner technologies, products and services which reduce environmental risk and minimise pollution and resource use (OECD, 1996*a*).

Despite the general lack of regular comparable official national statistical survey data, some broad trends in the industry can be described, drawing on a wide range of different sources. It must be kept in mind, however, that until better supply-side data are available, these trends are indicative only. Total turnover in the United States was over USD 100 billion in the mid-1990s and close to this figure in the European Union; the industry worldwide has been estimated to be larger in size than the pharmaceutical industry. In many OECD countries, the environment industry has displayed very high growth over the last 20 years. In the United States, growth has been around 5% per year in the 1990s, with highest growth in the segment of environmental engineering and construction. In Germany, which has the largest environmental market in the European Union, growth in the environment industry is estimated at 5-6% per year.

Forecasts often point to higher growth rates in the future in many countries. Growth is being driven by a greater emphasis on environmental regulation in a broader range of OECD countries, leading to large investments in pollution-control equipment and purchase of waste management services and, more recently, services to improve firm-level environmental performance. There is also greater emphasis by firms on pollution-prevention strategies and environmental planning, driving new technological developments and opening up new markets. Firms are investing in environmental equipment and services to improve efficiency in their use of resources, and enhance their public image as well as to comply with government regulations.

It is estimated that the environmental goods and services industry directly employs about 1% of the total OECD labour force. Studies of direct employment on the supply side report over 1.8 million people employed in the United States and the European Union combined (not including environmental services in some countries, and excluding clean technologies). Employment is estimated to have grown by 10% per year in the United States and by 3% per year in Canada and Japan in the first half of the 1990s, and in Canada total employment of businesses producing environmental goods and services increased by 15% in 1997 alone. In the OECD area, it appears as if less than one-half of these jobs is in manufacturing (including construction) and well over one-half in services. Most employment is in solid waste management and wastewater management. On average, job opportunities appear to be more highly skilled than in other industries, with a high share of engineers and technicians and business services occupations, but there is also substantial potential for low-skilled workers, *e.g.* in waste management and recycling. Shortfalls in skilled personnel for the environment industry have been forecast at various times because of the high use of professional, technical and skilled staff in many segments of the industry.

Continued growth in the environmental goods and services industry will be highly dependent on technological innovation to efficiently adapt goods and services to new regulatory and customer requirements, on supply and upgrading of skilled labour and on national and international adoption of environmental regulations and standards. Overall, demand for environmental products is gradually moving away from end-of-pipe solutions towards process and product modifications that are progressively cleaner and less environmentally harmful than existing solutions. It has been suggested that 50% of the environmental goods and services that will be used in 2010 have not yet been invented – which poses additional difficulties in defining, measuring, analysing and understanding this industry.

III. DEFINING THE INDUSTRY

Many studies have attempted to quantify the impact of the environmental goods and services industry on economic growth. However, identifying this industry is not straightforward because enterprises engaged in many different industrial activities are involved in producing environmental goods and services. Some are firms specialising in this area, while others operate in traditional industries with low specialisation in the environment. Some firms produce environmental services for their own use; others, which used to do so, now outsource this activity. Only if all environment-protection-related activities can be identified, *i.e.* those by specialist firms, those by non-specialist firms in other industries, and those produced by firms for their own internal use, can we begin to speak of an "environment industry" with some precision.

Further, because many of the products used for environmental protection are multi-purpose, it is impossible to identify a set of products as being exclusively and exhaustively used for environmental protection. This means that to measure the industry it is neither possible to point to an environment industry or to environmental protection products exclusively and exhaustively within the International Standard Industrial Classification of activities (ISIC), or the Central Product Classification (CPC), nor to use standard statistical collections based entirely on existing classifications. New techniques have to be developed in order to identify as closely as possible enterprises, activities and products involved in the environment industry.

A first task is to develop a working definition of the environment industry, as follows:

> *The environmental goods and services industry consists of activities which produce goods and services to measure, prevent, limit, minimise or correct environmental damage to water, air and soil, as well as problems related to waste, noise and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimise pollution and resource use.*

In general, it is not possible to exclusively or exhaustively identify environmental goods and services. One problem is that for cleaner technologies, products and services, there is currently no agreed methodology that allows their contribution to be measured in a satisfactory way. A further problem is that many goods that may be used for environmental protection, for example pumps, may also be used for quite different activities, and some goods which at first sight may seem unconnected with the environment may in certain applications be used for environmental purposes.

Information on the environmental goods and services industry should be classified in a way that allows a breakdown into *principal, secondary and ancillary activities*. The firms that are of interest in identifying the environmental goods and services industry are those which produce significant amounts of products deemed to be actually or potentially useful for environmental protection. This is a variation on usual practice in national accounting whereby firms are allocated to industries according to the principal (main) product. Relatively few firms are so specialised that they produce only a single product and those that are tend to be very small. Larger firms almost always produce one or more secondary products. If we measure only the activity of all firms whose principal product is environmental, we may include non-environmental secondary products and exclude environmental secondary production from non-environmental firms. To minimise exclusion of the latter, it is possible to be more inclusive in the definition of the "industry" by specifying "significant" production rather than main production of environmental products.

In addition to principal and secondary products, most firms also produce ancillary services, the output of which is not intended for use outside the enterprise. An ancillary activity is undertaken within an enterprise to create the conditions within which the principal and secondary activities can be carried out (*e.g.* record-keeping, purchasing of material and equipment, hiring, training, managing and paying employees, cleaning and maintenance of buildings and other structures, etc.). An ancillary activity may grow to the point that it has the capacity to provide services outside the enterprise. For example, a waste management unit may develop in-house capabilities for which there is outside demand. When an ancillary activity starts to provide services to outsiders, that part of the activity which produces output for sale has to be treated as secondary rather than ancillary.

In the same way, an enterprise may have to choose between undertaking ancillary activities which provide supporting services for its principal or secondary activities or purchasing such services from a specialist service producer. In this case, if ancillary activities are not separately considered, institutional changes which lead to the outsourcing of ancillary activities may be interpreted as growth rather than as a substitution of internal (ancillary) activities by external (market) transactions. There is some evidence of a trend towards outsourcing of previously ancillary environmental activities or vice versa as a result of economic forces, including the introduction of more stringent environmental regulations. This suggests that there is a need to provide, wherever possible, separate information on ancillary activities.

It is also desirable to break down statistics into *public and private activities*. Ownership structures in the environmental goods and services industry differ widely across countries. This is particularly true for the provision of environmental services. For example, public shares of municipal waste management range from some 25% in Spain and France, to 85% in countries such as Denmark and Portugal. Similarly, the public sector share of municipal wastewater management ranges from 15% of the market in the United Kingdom, to 95% in Germany (Drouet, 1997*a*).

There is evidence of a trend towards privatisation, either through increased subcontracting to private institutions or through full privatisation of environmental activities. If data collection and analysis cover only private activities and ownership, then changes resulting from privatisation (or contracting out) of activities previously carried out in the public sector could lead to overestimation of the environmental goods and services industry private sector growth rates. Distinctions between private and public ownership, and measurement of both, provide the information necessary to avoid such mis-interpretation.

Where these recommendations cannot be applied in full, it is suggested that studies and analytical results clearly label the types of activities that are described (private, public, etc.), and furnish some indicators for the trends in privatisation or outsourcing in order to ensure correct interpretation of the data.

Another issue is to make data collection responsive to *policy concerns*. For example, if policy makers are interested in understanding the industry's contribution to economic growth, the aim of the enquiry will be to obtain information about its relative impact, in which case annual growth rates for the industry (for turnover, value added, employment, etc.), will be the most appropriate economic variables (see Table 1). In general, information should be collected for the following standard

Table 1. **Correspondence between policy questions and economic variables**

Policy questions	Variables/indicators
Environmental goods and services industry contribution to economic growth	Annual growth in turnover, value added, employment, etc.
Environmental goods and services industry production and employment	Turnover, value added, employment and type of jobs
Environmental goods and services industry contribution to international trade	Exports, imports, international direct investment, licensing agreements
Environmental goods and services industry contribution to regional, structural strategies	Turnover, value added, employment, etc., by region or industry structure
Interaction between R&D policy and environmental technology development	Environmental R&D as share of total R&D; new patents for environmental technology
Cost of environmental services	Price per unit of environmental services (*e.g.* USD/tonne of treated waste)
Barriers to international competition in the provision of environmental goods and services	Share of the market served by local suppliers or monopoly suppliers
Ability of environmental goods and services industry activities to meet environmental protection goals	Environmental industry activities linked to environment indicators
Environmental goods and services industry contribution to sustainable development	Preventive activities' (*e.g.* cleaner technologies and products) share of total environmental industry output
Environmental goods and services industry and innovation	Environmental goods and services industry R&D and investment expenditure, non-economic data, *e.g.* patent counts
Ownership, concentration and structure of the environmental goods and services industry	Number and size of producers by ownership (domestic/foreign, public/private), mergers and acquisitions

Source: Based on Drouet (1997*a*).

economic variables to enable basic analysis of the environmental goods and services industry: turnover, employment (if possible by skill level or occupational classification), investment, exports, and research and development. For a full analysis of the industry, the following further information would be helpful: innovation (from innovation surveys), patents (from national or international patent statistics), state aid for industry promotion and exports (from government sources), and mergers and acquisitions (from structural statistics, or from specialised consultants and financial analysts).

IV. MAPPING AND CLASSIFICATION

In classifying the environmental goods and services industry, a major concern is to provide a system which is accurate and useful and which can be adapted to future needs. This industry is forecast to experience substantial structural changes, including concentration, privatisation, a shift away from the production of end-of-pipe equipment to the invention of new, integrated and cleaner technologies, and a move to totally new activities (*e.g.* environmental services). To achieve a flexible classification system which will capture such changes, the environmental goods and services industry is classified according to the matrix shown in Table 2. This matrix combines general categories of business activities of different kinds (columns) and the related environmental goods and services activity classes (rows). It can be modified and adjusted to better reflect the structure of the environmental goods and services industry in different countries at different moments in time.

Table 2. **Mapping environment activities**

	Business activities			
Environmental goods and services classes	Production of equipment and specific materials	Provision of services	Construction and installation of facilities	...
Pollution management group				
Air pollution control				
Wastewater management				
Solid waste management				
Remediation/clean-up of soil and water				
Noise/vibration abatement				
Monitoring, analysis, assessment				
Cleaner technologies and products group				
Resource management group				

Source: OECD and Eurostat, 1999.

In classifying the environmental goods and services industry, activities have been grouped on the basis of two main guidelines: *i*) the clear environmental purpose of goods or services supplied by the industry; and *ii*) ease of statistical assessment of these activities and products. The first guideline distinguishes between activities or products which directly aim to protect the environment and have a clear positive impact on environmental protection, and those which are carried out for other reasons but which can also be used to protect, or are beneficial, to the environment. This guideline is particularly useful in identifying multi-purpose products (*e.g.* pumps, and products such as more energy-efficient cars), or activities and products provided by highly diversified enterprises.

The second guideline provides a practical and cost-effective approach to data collection. The collection of information and the international comparability of data should be time- and resource-efficient. Therefore, if the assessment of a particular class of environmental goods or services is likely to produce imprecise or ambiguous results and is resource-intensive, it may be more convenient to neglect it for the time being (*e.g.* cleaner technologies and products). In accordance with these guidelines, the environmental goods and services industry can be divided into three main groups: a "pollution management" group, a "cleaner technologies and products" group and a "resource management" group.

The *pollution management group* comprises goods and services that are clearly supplied for an environmental purpose only, that have a significant impact in reducing polluting emissions and that are easily statistically identifiable. This group represents the core of the environmental goods and services industry, as all activities have as their main aim to protect the environment and data can usually be relatively easily collected. The classification of goods and services in the pollution management group is given in Box 1.

The *cleaner technologies and products group* comprises goods and services which reduce or eliminate environmental impacts, but which are often supplied for other than environmental purposes and for which statistical assessment remains disputed, difficult or expensive. The classification and collection of data for the cleaner technologies and products group is still in the development stage. This group essentially consists of production of equipment, technology, specific materials or services for cleaner/resource-efficient technologies and processes and cleaner/resource-efficient products.

The *resource management group* comprises goods and services which may be associated with environmental protection, although their prime purpose is not environmental protection (*e.g.* energy saving and management, renewable energy plants or indoor air pollution control). This group will most often be an optional addition to collection of data, and its inclusion will depend on policy interest and statistical feasibility. The classification and collection of data for the resource

Box 1. **Classification of *pollution management* equipment and services**

Production of equipment and specific materials for:

- Air pollution control.
- Wastewater management.
- Solid waste management.
- Hazardous waste collection, treatment and disposal.
- Waste collection, treatment and disposal.
- Waste recovery and recycling (excludes manufacture of new materials or products from waste and scrap).
- Remediation and clean-up of soil, surface water and groundwater.
- Noise and vibration abatement.
- Environmental monitoring, analysis and assessment.
- Other.

Provision of services for:

- Air pollution control.
- Wastewater management.
- Solid waste management.
- Hazardous waste collection, treatment and disposal.
- Waste collection, treatment and disposal.
- Waste recovery and recycling (excludes manufacture of new materials or products from waste and scrap).
- Remediation and clean-up of soil, surface water and groundwater.
- Noise and vibration abatement.
- Environmental R&D.
- Environmental contracting and engineering.
- Analytical services, data collection, analysis and assessment.
- Education, training, information.
- Other.

Construction and installation for:

- Air pollution control.
- Wastewater management.
- Solid waste management.
- Hazardous waste collection, treatment and disposal.
- Waste collection, treatment and disposal.
- Waste recovery and recycling (excludes manufacture of new materials or products from waste and scrap).
- Remediation and clean-up of soil, surface water and groundwater.
- Noise and vibration abatement.
- Environmental monitoring, analysis and assessment.
- Other.

Source: OECD and Eurostat, 1999.

management group is still in the development stage. This group essentially consists of production of equipment, technology and specific materials, provision of services, and construction and installation for: indoor air pollution control, water supply, recycled materials (manufacture of new materials or products from waste or scrap, separately identified as recycled), renewable energy plant, heat/energy saving and management, sustainable agriculture and fisheries, sustainable forestry, natural risk management, eco-tourism and other (*e.g.* nature conservation, habitats and biodiversity).

In the OECD/Eurostat Manual, the environmental goods and services industry is classified according to the economic activity undertaken which reflects the structure of enterprises supplying environmental goods and services (OECD and Eurostat, 1999). The basic structure is as follows:

– L*evel* 1 distinguishes the three main groups: A. Pollution management; B. Cleaner technologies and products; C. Resource management.
– L*evel* 2 distinguishes the main categories of environmental protection business activities: production of equipment and specific materials, provision of services, construction and installation.
– L*evel* 3 comprises the main classes of environmental protection activities: air pollution control, wastewater management, solid waste management, remediation and clean-up of soil surface water and groundwater, noise and vibration abatement.

V. DATA COLLECTION METHODS

Different approaches may be used to collect data on the environmental goods and services industry. The *supply-side approach* is characterised by the collection of information on the supply of goods and services for environmental protection, principally by means of targeted surveys of environmental goods and services industry producers. The *demand-side approach* is characterised by the collection of information on the demand for goods and services for environmental protection in the form of data on environment protection expenditure. The *integrated supply and demand approach* combines information available on both the supply and demand sides and attempts to reconcile this information in a consistent accounting framework to fill gaps and provide a comprehensive picture of the industry's activities and products.

Historically, the supply-side approach has been used by statistics-gathering bodies within governments to collect information on manufacturing enterprises (often collected by government Industry Departments) and on environmental services (often collected by government Environment Departments). Statistical offices have tended to use the demand-side approach and have only recently started to launch more comprehensive supply-side surveys (*e.g.* Canada, France, Germany, the United States). Outside government, business associations frequently survey their members in manufacturing or services.

To identify the best method or combination of methods for data collection, the methods should be evaluated on the basis of the following criteria: *magnitude of business activities* which constitute this industry; *data coverage and collection efficiency* (extent and level of detail of information needed for the analysis and relative costs in terms of resources and time to collect these data); and *economic variables and data quality* (each method has its strengths and weaknesses in delivering information on specific variables). Regarding the first criteria, Table 3 shows OECD average relative weights of business activities of the environmental goods and services industry. Equipment manufacturing and provision of services together constitute some 70-80% of the environment industry. Methods which provide comprehensive data for equipment manufacturing and provision of services will give a better idea of the size and structure of the industry as a whole than will methods which only cover, for example, engineering and research and development, since the latter represent only a small fraction of the industry.

Table 3. **Typical structure of the environmental goods and services industry**

Environmental goods and services industry business activities	Share of the total environment industry
Equipment manufacturing	25-35%
Provision of services	40-50%
Research and development	2-4%
Engineering services	5-10%
Construction and installation of facilities	15-25%

Note: Shares are based either on value added or on employment. These indicative estimates are derived from the results of environmental goods and services industry surveys and studies in OECD countries.
Source: Drouet, 1997*a*.

The *supply-side approach* is the best method for data collection as far as data coverage and quality are concerned. Here, it is possible to collect detailed information covering most relevant economic variables (*e.g.* turnover, employment and exports by environmental class, by size class of enterprise and with reference to standard industrial classifications, R&D) for most environmental goods and services industry classes. Direct surveys will also provide reliable information on public and private research and development. However, specific surveys present some inconveniences. For example, they do not capture all turnover (*e.g.* secondary and ancillary activities) and all employment effects of environment protection activities. They most easily survey information for turnover and labour employed directly in the production of goods and services when these are marketed and are less effective in measuring values for the same variables when activities are non-market, ancillary or multi-purpose.

Furthermore, double counting is a problem specific to supply-side surveys with respect to turnover estimates. For example, if filter cloths and complete filters are both included in the list of environmental goods, the same filter cloths may be counted twice. This problem is particularly severe in the field of waste management as this field is characterised by complex relationships among public and private waste collectors, specialised waste treatment operators, waste recycling firms, etc. Also, survey results often include information relating to secondary, non-environmental activities. Even if it is possible to exclude this output, it may be difficult to separate out the labour and other costs according to whether they are connected to the environmental or the non-environmental output. Although supply-side surveys of environmental goods and services enterprises deliver the largest amount of information, they are time- and resource-intensive. A comprehensive supply-side survey may cost several hundred thousand dollars and may take one to two years to design and conduct.

In general, when collecting data on the basis of a supply-side survey, it is recommended that the following issues be borne in mind:

a) A detailed classification and a detailed list of unique goods and service items should be specified on the basis of the definition and the classification (for an example of a detailed breakdown of the industry, see OECD and Eurostat, 1999).

b) A universe and a practical survey population should be established. This phase, although time-consuming, is crucial as a complete list of all suppliers of environmental goods and services is not readily available; the majority of the larger enterprises producing environmental goods and services are not specialised; and many enterprises are unable to specify whether their products are multi-purpose and used for environmental or other purposes (*e.g.* filters and pumps). Since the statistical office's register of businesses and organisations is unlikely to be a very useful unique source of information in itself, other sources must be used, such as industry association lists, government lists, catalogues of environmental product suppliers, etc. T*he sample should be as representative as possible* of the structure of the environment industry, *i.e.* it should include private and public enterprises, small, medium and large enterprises, etc.

c) Collection units (enterprises, establishments, business units) should be specified, for example following suggestions presented in the International Standard Industrial Classification of all Economic Activities (ISIC Rev. 3).

d) The surveys should collect, at a minimum, data on three economic variables: turnover (by environmental class); employment (by number employed); and exports.

e) The questionnaire should include a full explanation of the reasons for and aims of the survey, as well as instructions on how to compile answers to avoid inappropriate responses.

f) An evaluation of costs against coverage should be carried out.

g) Wherever possible, correspondences between the environmental goods and services industry definitions and related detailed classifications and existing detailed national and/or international industry and commodity classifications should be made.

D*emand-side approaches* can also help to provide and improve data on the environmental goods and services industry. The demand-side approach provides a view of the industry through data on expenditure for pollution abatement and control and other expenditures related to environmental protection. In many countries, standard statistical systems have been better developed on the demand side, so that extensive data on environmental expenditure are already available. This approach is based on a comprehensive national accounting system for environmental demand (see OECD, 1993). The United Nations has proposed the System for Integrated Environmental and Economic Accounting (SEEA) as a satellite system closely related to the core of the System of National Accounts (SNA). This system is designed to measure environmental impacts on the whole economy.

By using demand-side information (principally statistics on environment protection expenditures), it is possible to estimate supply-side data for broad parts of the industry. Data on expenditures for pollution abatement and control can be manipulated by applying engineering estimates of typical cost structures, *e.g.* by estimating the share of construction and installation in total environmental investment expenditure to extract information on the environmental goods and services industry. These ratios can then be applied at the level of the main sub-classes – wastewater treatment plants, sewer systems, solid waste treatment facilities, etc. This approach ensures consistency and provides information on most economic variables for the industry as a whole. It allows assessment of secondary and ancillary activities; avoids the problem of having to identify and estimate environmental shares of multi-purpose goods; and eliminates double counting. However, interpretation of the results is subject to the assumptions implicit in the estimations and for this reason, the data may be inaccurate.

Demand-side approaches may be used to obtain data on supply-side employment. To do so, expenditure has to be transformed first into domestic production and then into employment. The estimation of domestic production (as opposed to domestic consumption) poses difficulties in the calculation of exports and imports.

The second step requires information on labour productivity, which implies the need to disaggregate production by sector. Average productivity for broad industry aggregations may be used as an approximation for the environment industry (Blazejczak and Edler, 1997). This approach is a useful adjunct to supply-side measurement to cross-check the information collected and is an important source of data for assessing parts of the industry that are otherwise difficult to capture (*e.g.* secondary and ancillary activities).

Demand-side approaches will pick up all environmental protection goods and services expenditure irrespective of the source and will exclude the production of non-environmental goods and services even when this comes from principal producers of environmental goods and services. Although it may be fairly straightforward to measure the amount of money spent on environmental protection, demand-side approaches may be unable to precisely identify the products concerned. For both supply- and demand-side estimates, measuring ancillary activities may present problems in practice. Theoretically, such activities should be included in both measures. An example of a case in which the demand-side estimate may exceed the supply-side estimate is that of an enterprise which does not supply any environmental protection goods and services for sale but nevertheless has a significant amount of ancillary production of environmental protection goods and services for internal use. For these reasons, it is desirable to separate the use and production of ancillary services from transactions involving the sale and purchase of environmental protection goods and services.

An *integrated supply and demand approach*, using both supply-side and demand-side data, will combine the strengths and reduce the weaknesses of the two approaches taken separately. Combining supply- and demand-side data makes it possible to provide a more consistent picture of the total turnover and employment in the environment industry. Moreover, this integrated approach may help in assessing the turnover and employment effects of cleaner technologies as well as the indirect effects, by providing a sound basis for estimates. By integrating supply-side information with expenditure/demand for environmental goods and services, it is possible to obtain a general and aggregate picture of the environment industry, although it may be rather weak on detail and require further detailed investigations. The integrated demand/supply approach can be developed at a deeper level of detail by using data on environmental protection expenditure and integrating the data available on the supply side together with engineering data and case studies for both supply and demand (Pasurka and Steurer, 1995). The results obtained through the use of engineering modelling data are more complete and balanced, but require more time and work. The strength of this approach derives from the use of Input-Output tables and techniques. It allows data gaps on the supply side to be filled to a considerable extent. Overall, this approach can provide a complete picture of the industry including the impact of cleaner technologies and the importance of the secondary activities of enterprises.

In addition, *other methods* may be used when economic data are not available either on the supply side or the demand side. For example, information on turnover can be estimated by combining physical output data with average price or cost ratios. This approach can be applied only for the provision of services category and to some extent to equipment (*e.g.* based on data on newly installed treatment capacities), and the results will generally be very approximate. Other information sources can be used to improve the quality of data on the environment industry. For instance, in the case of R&D, information can be obtained by using data on research outputs – *e.g.* based on scientific citation indexes or on patent registers. Information on state aid for industry promotion and exports and mergers and acquisitions will have to be extracted or estimated from a variety of other surveys or databases.

Other sources: Some data may be collected as part of routine statistical surveys of those categories of standard statistical classifications which separately identify parts of the environment industry. For example, some environmental services such as recycling and sewage and refuse disposal are separately identified in the United Nations International Standard Industrial Classification of all Economic Activities and the United Nations Central Product Classification, and these may be routinely collected (see OECD and Eurostat, 1999, for further details). Furthermore, the Harmonized Commodity Description and Coding System (HS) for international trade enables the identification of codes related to environmental goods, although no services are included in this system (see OECD, 1998, for further details).

Information on the environmental goods and services industry can also be obtained by extraction and manipulation of data from existing statistical collections or by adding specific questions to existing data collection exercises. Some countries have obtained information about specific environmental services by including additional questions in other data surveys. For example, a survey on the legal services industry could ask respondents to split income by source and to include environmental law as a separate category. This kind of approach is reasonable for a rapid, low-cost investigation of part of the environment industry, but it does not provide a comprehensive view of the whole industry within a common framework and common reference period.

Other possible sources of statistical information are organisations that routinely collect environmental information as part of their usual activities. Environment protection agencies usually collect some relevant data as part of their monitoring and regulation programmes. Government organisations responsible for employment and training policy may obtain data from businesses through various environmental-employment-generation programmes. Further information may be obtained from databases on research and from development projects for waste management and pollution control. Trade associations regularly issue information on parts of the industry, and some associations regularly publish data on their members. Often, such data are highly detailed on physical parameters although in some cases economic data are also available (number of suppliers, turnover, and employment). However, trade association data are usually narrowly class-specific.

VI. ACCOUNTING FOR CLEANER PRODUCTION

So-called "clean technologies" are generally those techniques integrated into equipment or products to prevent pollution at the source rather than cleaning it up afterwards through add-on features. They are part of the design of the process or product in question. The apparent slowdown in the growth of the classical end-of-pipe equipment industry and the interest in a more integrated regulatory approach to environmental protection suggest the increasing importance of cleaner technologies and products. However, the definition, identification and measurement of integrated or cleaner technologies have proven difficult. Cleaner technologies and products are determined with reference to "standard" technologies and products. In a dynamic perspective, the cleaner technologies and products of today will become the "standard" technologies and products of tomorrow. Moreover, the question of the proportion of, for example, turnover in cleaner technologies and products that should be attributed to the environmental protection industry (*e.g.* how to measure the environmental part of cleaner cars) remains open to discussion.

A number of methods which can be used to account for cleaner technologies and products have been identified. Although these approaches are relatively comprehensive and consistent with the aim of defining and assessing cleaner technologies and products, they are either limited or still at an experimental stage. These include:

1. Measurement of R&D, *innovation and engineering efforts* to improve environmental performance of technologies, processes and products. This would focus on *measuring* R&D *and related innovation and engineering costs*. R&D, innovation and engineering costs are not always possible to obtain, particularly in the business sector. Nevertheless, some R&D surveys do already capture these values and respondents indicate – in budgetary or full-time equivalent employment terms – specific environmental research, innovation or engineering efforts.
2. Measurement of *efforts* to improve environmental performance by measuring the incremental cost of cleaner technologies and products. This considers "cleaner" technologies and products, which, from an expenditure point of view, are *more costly* than the equivalent less-clean alternative products. Only the extra costs are considered as environmental protection expenditure. This requires comparing the price of the clean product with that of the superseded item. However, from a supply-side perspective, technologies which are less polluting could also be less costly.

3. *Creation of a list of cleaner technologies and products.* This approach consists of creating a comprehensive list of dedicated cleaner technologies, processes and products. For example, the Dutch Ministry of Finance has developed a list of cleaner technologies which is updated each year, to implement a tax-incentive system for cleaner production investment. This could be complemented with an *eco-labelling approach* based on labelling procedures, once these are complete and effective. However, the eco-labelling approach is currently impracticable for many reasons (*e.g.* slow product identification, difficulties in defining unambiguous criteria and methodologies for the labelling procedure, under-representation of SME products). Similarly, "leading market edges" could be measured. This approach attempts to measure, for each product group, that part which is considered as the "leading green edge" of the market, based on current standards. For example, in the field of construction, the market share of low-energy houses could be estimated.
4. *Physical assessment.* This approach consists in measuring and evaluating reductions in pollutant emissions and waste generation due to cleaner technologies, and placing an economic value on these reductions (*e.g.* savings in disposal costs).

VII. CONCLUSIONS

The environmental goods and services industry is increasingly important to both economic performance and sustainable development in OECD countries, but the assessment of this industry and the formulation of appropriate policies has been hampered by the lack of a clear definition and collection of relevant data. As a first step, the OECD/Eurostat Manual proposes a definition and classification of the environmental goods and services industry, describes methods for data collection and recommends best methods and approaches for analysis (OECD and Eurostat, 1999). The definition and classification aim to be as complete, flexible and operational as possible in order to measure the environment industry as it currently stands, while allowing for future structural changes, such as shifts from end-of-pipe to cleaner technologies or the development of new environmental services. The intent is to provide national statistical offices and researchers with a toolbox that allows flexible adaptation to specific national situations in terms of policy interests, data availability, research budgets and structure of the industry.

However, this is still "work in progress" as the statistical assessment of the environmental goods and services industry is complex. Available approaches and data are limited, incomplete and not always comparable across countries. Accounting for certain classes of environmental goods and services, such as cleaner technologies and products, remains difficult and/or laborious. In the future, solutions to these problems may be found based on the experience gained in data collection. For example, the implementation of new classifications of industrial activities and products (*e.g.* the North American Industry Classification System, the UN Central Product Classification) is ongoing. Important new data collection exercises on the environmental goods and services industry have been undertaken or are planned in a number of countries (*e.g.* France, Germany). The OECD/Eurostat Manual will be revised if there is sufficient practical experience to show that the definition, classification or methodologies have become out of date or are not operational.

Three statistical areas which merit further consideration are those of cleaner technologies and products, dual-use products and international trade. The definition, identification and measurement of clean technologies – those integrated into processes and products – will continue to pose difficulties but various methodologies could be combined to yield measurement approximations. Dual-use and multi-purpose products are those products that can also be used for non-environmental purposes (*e.g.* filters, pumps, and pipes); these products have been estimated to account for a considerable share of sales of environmental equipment and goods. Information on multi-purpose products may best be obtained by surveying the final user since environmental suppliers and investors are not always able to assess that part of the sales of the product that is for environmental protection. Another approach to assessing dual-use and multi-purpose products is to match the results from supply- and demand-side approaches.

Nor is international trade in environmental products and services easy to measure. Supply-side surveys provide the most comprehensive information on *exports* of goods and services, but available data remain limited in accuracy and detail. The analysis of trade codes based on standard foreign trade statistics provides useful indicators of the direction and change in magnitude of imports and exports by country of origin and destination. However, flows of services are not covered, and goods trade flows are underestimated because only a few traded goods codes can be separately identified as solely for environmental purposes. Although the two approaches together will provide useful information, data is still missing on trade in cleaner technologies and products and multi-purpose products as well as information on other important aspects of globalisation such as foreign direct investment, and payments for patent and other intellectual property rights for the use of environmental equipment.

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GOVERNMENT PURCHASING OF CLIMATE-FRIENDLY TECHNOLOGIES

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This article is exerpted from a larger study prepared by Sara Eppel, consultant, Paris, France for the Climate Technology Initiative (CTI) administered by the International Energy Agency (IEA).

I. INTRODUCTION

In several OECD countries, the national government is either the largest or one of the largest single actors in the economy, accounting for 10-25% of GDP. In Canada, for example, the federal government has an annual energy bill exceeding CAD 800 million, with 59 000 buildings and facilities, and 25 000 motor vehicles costing CAD 21 million and emitting 92 kilotonnes of CO_2, and annual purchases of goods and services of over CAD 8 billion. This scale of purchasing is not untypical of many OECD countries. If governments as purchasers of a wide range of technologies were to systematically choose climate-friendly technologies for use in their own buildings and vehicles, the potential for governments to have a major impact on the technology market for environmentally friendly products would be substantial. This article is taken from a larger study which is part of an effort being undertaken by the member countries of the Climate Technology Initiative (CTI) on *Enhancing Markets for Climate Friendly Technologies*. The CTI aims to promote the objectives of the 1992 UN Framework Convention on Climate Change (UNFCCC) by fostering international co-operation for accelerated development and diffusion of climate-friendly technologies and practices for all activities and greenhouse gases.

Because governments have a significant market share in OECD countries, their purchasing power, if directed towards climate-friendly technologies, could create increased demand for these products, and enable technology manufacturers to move towards mass production of their products. For some technologies the higher capital costs of climate-friendly products, in comparison to higher energy consuming products, is a major barrier to their more widespread deployment. Mass production would lead to reduced manufacturing costs and reduced product prices, and would improve prospects for more widespread deployment of the technologies.

In recent years, OECD governments have recognised that their activities in their own estate are important for setting an example to industry, commerce and the public. For instance, Chapter 4 of Agenda 21 emphasises the important role which government purchasing can play in addressing the wider issue of unsustainable consumption and production patterns, of which climate change is one manifestation. As a result, OECD Member countries agreed in 1996 to improve the environmental performance of governments in which leadership through government purchasing is given a prominent place (OECD, 1996). OECD governments have recognised that their purchasing decisions not only make a direct impact on the market in terms of level of sales, but also send signals to other key stakeholders in relation to their energy and environment objectives. They recognise that it is difficult to advocate responsible environmental behaviour to others if they are not taking the same measures closer to home.

II. GREEN GOVERNMENT PURCHASING

In many instances, government purchasing strategies are motivated not by the objective of enhancing markets for climate-friendly technologies, but by the aims of making financial savings and meeting their domestic and international environmental objectives. These environmental objectives may arise from the need to meet the requirements of the UNFCCC which has stimulated government programmes for reducing national CO_2 emissions. Activities to reduce energy use in the government estate are part of the national programme to meet these international environmental commitments. In addition, and more broadly, government purchasing policies may also lie within an overall sustainable development strategy arising from commitments made at the Rio Conference in 1992.

However, statements by governments about the importance of meeting these environmental objectives are not currently matched by commitments to deploy climate-friendly technologies. These technologies encompass both technologies which use energy efficiently, thereby minimising emissions of CO_2, and technologies which utilise renewable sources of energy, or higher-efficiency clean-generation technologies. In the short to medium term, renewable energy can help to increase diversity of energy supplies worldwide but is unlikely to provide a significant proportion of energy supplies overall. Nevertheless, the increased contribution of renewable energy and clean-generation technologies to global energy use is seen by many as one of the most important changes required to move towards sustainable development.

Government purchasing choices range from major decisions, such as the choice of a boiler for heating and hot water in a new or refurbished building, to decisions about improving the energy efficiency of a building's lighting, the choice of new computers in an office, or washing machines in a residential care home. Such choices are influenced by several factors:

– *Cost* (generally the overriding factor). This may not be limited to just the capital costs as operating costs will also affect the decision.
– *Technology availability*. This includes basic knowledge of the available technologies and how they can be installed and maintained.
– *Performance of a technology*. In terms of its ability to meet the users' needs, to reduce operating costs and to be maintained.

– P*erceived risk* of purchasing a technology whose track-record is not well proven in the same applications as the intended use.

Most OECD countries have over the years implemented programmes to encourage the development and deployment of renewable energy technologies and energy-efficient technologies on a national scale. Governments have supported a variety of programmes ranging from research and development projects to subsidies, tax relief, rebate schemes, information programmes, etc., to enhance the deployment of such technologies. Through these programmes, governments have been seeking to:

– Strengthen the renewable energy industry's technical capabilities to achieve successful technical advances.

– Build up the renewable energy technology industry to be self-sustaining and competitive in the marketplace.

– Gain a strong technology supply industry which will be able to compete in the international technology market.

– Contribute to meeting the national environmental goals for greenhouse gas emission reductions, and a sustainable energy supply.

– Comply with environmental standards for conventional pollutants, etc., by achieving concomitant reductions in sulphur dioxide, oxides of nitrogen, and particulate emissions, achieve improved water quality, etc.

Governments increasingly recognise that deployment of renewable energy technologies and other climate-friendly technologies is essential if they are to meet their environmental objectives for limiting greenhouse gas emissions and working towards a sustainable energy economy. Yet there remain numerous financial, institutional and other barriers to greater green government procurement.

III. CLIMATE-FRIENDLY TECHNOLOGIES

Climate-friendly technologies are those technologies which reduce energy consumption, or which convert renewable sources of energy into heat or power, and which therefore lead to reduced emissions of greenhouse gases – particularly carbon dioxide (CO_2), the major greenhouse gas. With regard to governments, this includes energy use in buildings and appliances in government offices, public housing, schools and institutes of higher education, police and fire stations, prisons and corrective centres, hospitals and residential care homes and military sites. It also includes the fuel choices available for government or public sector vehicle fleets (including publicly owned agencies such as the postal service) and buses.

Buildings

The largest energy savings in buildings may be made from improvements in the energy efficiency of a boiler and heating system. Significant opportunities exist, therefore, for the deployment of technologies which will improve a building's energy use and reduce greenhouse gas emissions. The main sources of heating are currently boilers, air heaters, radiant heaters, electrical on-peak and storage heaters and room heaters. More recent technologies include: condensing boilers, gas, oil and air heaters, heat pumps, micro-combined heat and power (CHP) and solar thermal heating systems. All of these sources (except for air heaters) are also used for the provision of hot water, either as part of the output of a single appliance or as a separate system.

Solar energy can be a viable contributor to a building's total energy requirement, providing electricity for appliances, lighting, heating and cooling a building. Two solar-powered technologies are mature and are widely used in some countries: photovoltaics (PV) and solar thermal. Both technologies are found to be most acceptable (aesthetically and practically in terms of space needed for the equipment) for small-scale applications where they are integrated into the building's fabric as roof or wall panels. They are currently deployed across the range of climates which are experienced in OECD countries, with widespread use in sunny (Greece, Australia) and not-so-sunny (Austria and Norway) countries where they are used for water heating and for heating swimming pools.

Solar thermal technology for small-scale applications such as in government buildings involves the use of components to capture solar radiation and apply the heat where it is needed, such as for space and water heating. A variety of systems are available for use on buildings, but the most practical for small-scale applications are relatively cheap solar panels which can be mounted on the roof or wall of a building. Due to the seasonal variation of solar radiation, most systems also include heat storage or supplementary heating.

Solar photovoltaic technology produces a flexible form of energy which can be integrated with other sources of electricity via local, regional and national networks. It is also very successfully used in off-grid applications where it can be more cost-effective than extending electricity cables to remote locations. Solar PV consists of manufactured materials, usually formed into small assemblies or cells, which are light-responsive semiconductor devices that directly convert solar radiation into electricity. The PV unit can be made to the size most appropriate for its needs and is particularly well-suited to the roof-top installations that are most likely to be practical in government-owned premises.

The economics of PV are highly dependent on the location. Remote locations are currently those areas which are most likely to benefit from PV as the costs of connecting the area to the main grid are so high. PV is currently used quite extensively in remote locations in developing countries for lighting, refrigeration, and for operating radios and televisions. In OECD countries, PV is found in individual or network-linked schemes in urban areas as well as in off-grid locations.

Another option for heating is combined heat and power (CHP) or the simultaneous production (co-generation) and exploitation of high-quality energy (mechanical and/or electrical) and low-grade energy (thermal) from the same energy source. One of the most important aspects of CHP is its great economy of fuel use compared to the usual combination of boiler plant for heating and conventional thermal generation for electricity. CHP can be considered as an electrical generator incorporating a heat-recovery system, and the generator can be driven by a number of prime movers operating on a variety of fuels. The different prime movers are generally available in sizes ranging from those suitable for small building units which will utilise all the energy, to those for district heating systems where electricity will be exported to the grid. Conventional electricity generation in the United Kingdom, for example, has a conversion efficiency of approximately 35%, thus 65% of the primary energy input is rejected as low-grade heat. CHP utilises the heat, providing overall efficiency of 65-85%, and if it is used locally there will be negligible transmission and distribution losses. CHP is most effective when it is installed at the stage of a site's construction; later conversions can significantly reduce the plant's efficiency. In addition, the distance between the generation plant and the buildings receiving the heat and power is also critical to its efficiency. Pipe insulation is essential for minimising heat losses. If the CHP plant is located at some distance from the buildings it is serving, its efficiency can be little better than conventional electricity generation.

Air conditioning can be a major source of energy consumption. Where air conditioning is required, there are three types of system, each with many variations: centralised, where all heating and cooling is carried out in a central plant room and conveyed to the rooms by duct work; partially centralised air/water, where centrally cooled or heated air is further heated or cooled at entry to the rooms; and decentralised where all operations are performed locally. Variations and combinations of these systems can be used in any application, and choices exist for each of the component parts. An alternative to full air conditioning is the "mixed mode" approach, where some level of cooling is provided together with provision for natural ventilation. Different systems can then be operated at different times as internal and external loads change, thus avoiding unnecessary energy use.

In appropriate climates, heat pumps can be attractive in buildings such as those owned by central and local governments because they often have a cooling requirement in the summer and need heating in the winter. Reversible pumps are designed to meet these needs. Large premises enable a variety of technologies to be used, thus reducing the price per installed kW. The main barrier to the deployment of heat pumps is probably their initial capital cost, which can be between

1.5 and 5 times higher than a gas- or oil-fired heater of the same capacity, and the price differential for electric resistance heating is even greater. Today's low oil and gas prices make the differential between heat pumps and fossil fuel systems even more unfavourable. However, if a cooling system is required the cost differential is smaller and in new buildings the total cost of air conditioning and space and water heating will be considered, which makes heat pumps more attractive.

Windows offer another opportunity for energy saving. Glazing is generally regarded as the point from which much of a building's energy might be lost. To combat heat loss, occupants will use additional energy for heating the building. High-efficiency glazing in well-fitting frames are climate-friendly technologies by virtue of their contribution to minimising heat loss, maintaining the interior warmth of a building, reducing the need for increased heating and so reducing emissions of greenhouse gases from the energy source.

The thermal performance of windows is measured as a u-value. The lower the u-value (measured as $W/m^2.°C$), the better the thermal performance and the lower the level of heat loss. There are a range of options available to improve the thermal performance of windows, from double and triple glazing to evacuated glazing, and a range of transparent insulation materials (although some of these have poor light penetration). If properly installed, all of these windows should lead to a reduction in condensation and downdraughts, and should improve sound insulation compared with single glazing, depending on the size of the gap between the glazing sheets. The thermal performance of the window frame is also critically important for achieving maximum benefits. With a badly sealed window frame, draughts will still penetrate and, however good the glazing, the overall performance will be significantly reduced. Where the frame is well-fitting, durable and of a reliable material, the u-value of the frame can be higher than that of the glazing.

Lighting is a major energy consumer in buildings, and there is great potential for making energy savings and reducing CO_2 emissions. Many OECD countries have improved their energy consumption from lighting by replacing inefficient lamps with high-efficiency alternatives. Nevertheless there have continued to be improvements in the lamps on the market and governments could be advised to re-examine their lighting systems to identify further energy savings. In many cases, where efficient lamps have been installed there is still room for improvements in energy consumption with the use of motion sensors, time switches and dimmers. Several types of lighting appliances are available and widely marketed: incandescent lamps; tungsten halogen lamps (which offer a 30-35% saving in energy over the incandescent); linear fluorescent lamps which produce three to five times as much light and much less heat than incandescents; compact fluorescents which are energy-efficient fluorescents that are much smaller than standard fluorescents; induction lamps; and high-intensity discharge lamps.

Office equipment

Central and local government departments use an increasing number of office appliances. In many countries, office equipment (computers, printers, copiers, document scanners, fax machines) is the fastest growing electricity load in the commercial sector. In OECD countries, office equipment consumes nearly 80 terawatt hours/year of electricity, and in 1995 office equipment was responsible for nearly 30 million tonnes of CO_2. Computer equipment alone accounts for 5-20% of commercial energy consumption and this figure is expected to double by the year 2000. It is estimated that office equipment draws about 15-30% of a building's total building electricity. In view of the significant and rapidly growing contribution of these appliances to total energy consumption, measures to reduce the energy intensity of the equipment need to become more widely utilised across the OECD area. Any government strategy to reduce greenhouse gas emissions must include an examination of office equipment. Purchasing programmes of low-energy equipment by the public sector would significantly improve the market for these products, and encourage the adoption of low-energy equipment as the norm in the public and private sector.

Energy-efficiency standards and energy-efficiency labelling are two promising methods of reducing the energy consumption of appliances. In the case of office appliances, standards for the energy consumption of the equipment tend to be adopted on a worldwide basis because the market for these appliances is international. In addition, the market readily accepts improved standards of performance in these appliances because so many aspects of the appliances have already changed very rapidly, and continue to do so. Given the enormous market for office appliances worldwide, there is obviously significant potential for increasing the market share of the most energy-efficient models.

The most important near-term opportunities for improving the energy efficiency of copiers are the use of controls for: automatically shutting-off machines during non-work hours; automatically switching them into low-power mode during idle periods (but with quick recovery time); and making convenient, reliable and more rapid duplex (double-sided) copying the default mode for all but the very smallest machines. Substantial energy-efficiency savings can be made from additional improvements such as low-power sleep mode with rapid recovery, or a modular power supply; new features such as automatic scanning of the original to make duplex copies wherever possible; use of new imaging and printing technologies; and the use of external switches to power-off an existing machine after a period while not in use based on a "smart" control or room-occupancy sensor. One major contribution to cutting the energy consumption of office appliances is by switching the machines off overnight and on non-work days. A great deal of equipment is left switched on, sometimes because users erroneously think it improves the appliance's efficiency but more often through carelessness.

Personal Computers (PCs) and monitors each consume over 25% of the total office equipment energy use. The most important development for saving energy in PCs is in the use of technologies which slow or shut down various components after some user-defined idle time. The US Energy Star is probably the most developed programme which sets efficiency targets for computers. It evolved as a result of the variety of state standards which were causing difficulties and confusion for manufacturers. The Energy Star Programme is a voluntary partnership between the Environmental Protection Agency and computer manufacturers. The specifications in force since 1995 are that computers, monitors and printers whose output is less than or equal to 14 pages per minute should use no more than 30 W of power in stand-by mode, and that larger and colour printers should use no more than 45 W of power in stand-by mode.

Governments in the wider sense use many "domestic" appliances. Hospitals, residential care homes, prisons, correction centres, public housing in some countries, military sites, and further education residences all provide domestic appliances from public funds. Items such as refrigerators, washing machines and driers are routinely purchased, and can make a substantial contribution to the energy load of a building. Domestic appliances in the United Kingdom, for example, account for 13% of total energy use, and 54% of electricity in the domestic sector.

Energy consumption in domestic appliances is not generally a feature which is given high priority by government purchasers. In both domestic and commercial situations, greater consideration is usually given to features such as low noise, size and speed (in the case of washing and drying machines). Because the majority of their consumers do not demand low-energy use, manufacturers have little incentive to invest much effort into producing low-energy appliances, especially if such appliances would cost more and would thus appeal to a limited market. With careful consideration of the energy-efficiency characteristics of appliances on the market, purchasers could opt for the most efficient products which do not necessarily have the highest capital cost, and which certainly have lower operating costs, energy use and therefore lower emissions of CO_2 – the major greenhouse gas.

Vehicles

Emissions of CO_2 from vehicles have risen at the fastest rate of all emission sources over the last decade and are set to continue to rise. Some local authorities have introduced fuel switching from petroleum to alternative fuels in their own vehicle fleet. In addition to encouraging the use of alternative fuel vehicles, governments have a very prominent role in encouraging fuel efficiency in all their vehicles, irrespective of the fuel used. Many OECD governments recognise this and have implemented policies to educate their vehicle drivers in fuel-efficient driving habits, to organise their operations to minimise vehicle usage, and to improve maintenance of the vehicles to avoid pollutant emissions. Some governments, such as Canada and Japan, have considerably reduced the size of their government vehicle fleets as part of their review of environmental considerations in government activities. Another purchasing issue which governments need to consider is the use of air conditioning in vehicles. The amount of fuel used by the vehicle increases significantly when air conditioning is in operation, and when vehicles are bought or leased, purchasers should give due consideration to the real need for this facility, against its environmental impacts and increased fuel use and costs.

IV. BARRIERS TO GREEN GOVERNMENT PURCHASING

Within governments, the main factors which inhibit higher levels of green government purchasing include cost factors, institutional barriers and information deficiencies. Because climate-friendly technologies remain, in many cases, a higher capital cost purchase than their more polluting alternatives, the market for the technologies remains small. Until the market for these technologies grows, large-scale production is usually not possible, preventing economies of scale and a reduction in the price of the technology. Once the small production companies grow, increased demand and increased sales should translate into lower production and also marketing costs, which comprise a significant part of today's purchasing price.

Many renewable energies are not currently competitive in cost terms in comparison with natural gas and other fossil fuels. In many countries, current electricity prices do not fully reflect the real long-term costs of provision. If the costs of external factors, such as environmental impacts or energy-security measures, could be reliably incorporated into energy system costs, renewable energy technologies would become more cost competitive. This issue is directly reflected in the decisions which purchasers make when considering replacement technologies. The *capital cost* of high-efficiency fossil-fuel-fired technologies can be higher than less efficient alternatives, and with the relatively low costs of fossil fuel energy, initial cost comparisons between the options can lead purchasers to buy low-efficiency technologies. However, if the life cycle costs of the system are assessed, incorporating the reduced operating costs over the system lifetime, many climate-friendly technologies can be more cost effective today than existing technologies. Some technologies have, however, gained a niche market and have become cost competitive in certain circumstances. For example, PV when used in remote locations is cost competitive in comparison with the costs of linking the location with the electricity grid or using conventional stand-alone equipment.

In addition, neither the technology purchaser nor the user is credited for the national environmental benefits which will accrue from the use of the technology. Until the "larger" government system credits users for their choice of a climate-friendly technology because of the environmental benefits, purchasers will continue to perceive only the higher capital costs of the technologies. There must, therefore, be some means of "rewarding", or at least reimbursing, the purchaser to provide a "level playing field" for green technologies.

Certain institutional arrangements can inhibit governments from purchasing climate-friendly technologies. This is because cost-effective arrangements which could overcome the initially higher capital costs and which would enable governments to purchase these technologies can not easily be made. For example:

- *Institutional interests*. Although energy-efficient technologies may have higher capital costs, they also have much lower operating costs than a conventional technology. However, this cost-saving factor is not taken into account in many government organisations where the budget structure may be such that any savings made in operating costs will benefit a leasing company or Department of Public Works, rather than the department which makes the capital purchase. Thus one department has to spend more for the capital cost of the technology, while another department benefits from the energy and operating cost savings.
- *Budget structures*. Some governments' budget structures discourage departments from pooling their orders for technologies. Significant capital cost savings could be made if central and local governments could form buyer groups to make bulk purchases of specified products, and thereby achieve cost discounts from manufacturers. In addition, bulk orders from a group of organisations guaranteeing a purchase over a number of years give manufacturers some security, because they know where at least some of the demand for their products will come from over that period.
- *Leasing arrangements*. Building leasing arrangements usually require the renegotiation of a lease when changes are made to energy practices, and private sector tenants in such buildings would have to agree to any energy management changes, which may be difficult to achieve. In addition, management fees for building space are sometimes paid as a percentage of costs, thus offering little incentive for departments and agencies to reduce operating costs.
- *Financial constraints*. In many central and local governments, short-term financial considerations prevail: a contract may be awarded to the lowest tender irrespective of other important factors such as long-term savings and environmental impacts.

Another factor relates to information gaps on the part of governments. Government purchasers, just like other purchasers of technology, make decisions based on information such as how effectively a technology performs in relation to the purchaser's needs, the capital and operating costs, how easily it will be operated, and how good the maintenance and after-service will be once it has been installed. However, gaining comparable information on all these criteria may not be at all easy for technologies which are not widely available on the market.

In many countries, purchasers do not have easy access to information about climate-friendly technologies, and so they opt for the easy option, thus losing the opportunity to reduce still further their greenhouse gas emissions. Adequate training of government purchasers to inform them at regular intervals about the available climate-friendly technologies would be an effective means of ensuring that informed choices are made. Information dissemination among technicians such as boiler operators, electricians and plumbers can be important for raising awareness of the characteristics and environmental and energy benefits of the climate-friendly technologies, and encouraging these technologies to be considered as viable alternatives to conventional appliances.

Utilities play an important part in influencing purchasers' technology choices and their promotional support for a climate-friendly technology can be critical to its success. Utilities have a captive audience of customers who are sent inserts and promotional literature with their bills, about space- and water-heating systems and other energy products. Their support for climate-friendly technologies has been shown to be very influential when demand-side management measures have been adopted by utilities, and when incentives have been offered to customers to buy products such as energy-efficient light bulbs.

Purchasers may also opt for a new product from a company with which they are familiar, from whom they receive good service, and whose products are not noticeably more expensive than those of their nearest competitor. If a new boiler is needed, a newer model is likely to be more efficient than the one it is replacing, but other more radical options would probably not be investigated, such as installing CHP technology, a heat pump, a condensing boiler, buying a smaller boiler after improving the insulation and draught proofing of the building, or using solar thermal technology for some part of the operation.

Even when the information barrier has been overcome, purchasers are frequently reluctant to invest in technologies whose benefits and operating costs are not yet well known. Purchasers are understandably unwilling to risk technologies which may prove not to fulfil the users' requirements, may break down and cost more to maintain than expected, and may soon become obsolete. For public purchasers, this risk is reinforced by their position as spenders from the public purse. Conservative decisions may be motivated by the fear of technology failure (particularly in relation to renewable energy technologies which are viewed as untried technologies), and criticism of government spending of taxpayers' money on ineffective technologies. In practice, most of the energy-efficient technologies and many of the renewable energy technologies available for deployment can be considered mature as they have already achieved a track record in a variety of applications. The technologies are now waiting for widespread deployment to achieve cost reductions and a genuinely competitive position in the market.

V. FINANCING TECHNOLOGY PURCHASING

One of the main barriers to the deployment of many climate-friendly technologies is cost. Renewable energy technologies are not generally cost-competitive in comparison with natural gas and other fossil fuels. The exception to this is applications in niche markets, where the deployment of PV in remote locations off the main electricity grid is often more cost effective than the cost of grid connection. Apart from renewables, many other climate-friendly technologies such as heat pumps, high-efficiency windows and lighting have a higher capital cost than their less-efficient alternatives. However, when the savings in electricity use, fuel costs and environmental damage are taken into account, climate-friendly technologies can be more cost effective than their alternatives.

For all public sector organisations, constraints on capital spending are an inhibiting factor in making improvements to government buildings, appliances and vehicles. To overcome this obstacle, several Member countries have implemented financing arrangements which have proved to be very successful in involving the private sector in the procurement of climate-friendly technologies for government facilities.

In the private sector, third-party financing using an Energy Service Company (ESCO) is a well-developed technique allowing a small company to benefit from the financial support of another company to permit an energy-related development. The ESCO must in such cases feel confident that they will achieve an attractive return on their own and the developer's investment. In Canada, for example, the federal government has formed partnerships with the private sector to minimise its capital costs while at the same time achieving its environmental objectives. In the United States, Executive Order 12902 on Federal Facilities recommends financing options such as energy savings performance contracting, rebates and third-party financing as attractive options.

Other measures can stimulate direct responsibility for energy costs and thereby encourage departments and agencies to make savings. The budget structure in some government departments means that savings in operating costs do not flow back to the Department which made the capital investments, but rather to a building leasing company or a Department of Public Works. Until changes are made to this arrangement, it will continue to be difficult to encourage departments and agencies to make capital investments, even if such investments meet larger energy and environmental goals. Pressure to make such changes in budgeting arrangements from within the organisation would be necessary, and using the support of elected councillors, for instance, can be a very effective way of forcing change. Similarly, governments may need to renegotiate building leases to make changes to energy practices. This effort would be worthwhile when the cost savings and the environmental impacts of changing to climate-friendly technologies are properly taken into account. In addition, the positive boost which governments could give to the industry by their purchases could provide the essential encouragement for the industry to expand its markets and achieve cost reductions for the technologies.

One of the main criteria for lowering the capital costs of many climate-friendly technologies is to achieve economies of scale in their production. By raising product output to mass production level, companies can sell their products at a significantly lower price and will thus increase their competitive position in the market, probably leading to greater deployment of their products. Governments at all levels could help climate-friendly technology companies to achieve this by forming purchasing groups to place bulk orders. For example, in Australia, a number of companies formed a buyer group, pooling their purchasing needs for a specified product and assessing their requirements over a five-year period. The buyer group then called on the production companies to offer them a favourable price for the product on the basis of the guaranteed sales over the five-year period. The billing has been organised separately for each member of the buyer group. This technique could be applied to purchases of climate-friendly technologies.

Governments at all levels could co-operate together and with the private sector to form a buyer group, so that central government departments, local governments, hospital management, education authorities, social services departments, etc., could operate as a single buyer group for specified products, and could identify their individual needs over a number of years. When grouped together in this way, these orders could provide a manufacturer with a large and guaranteed market over a period of time. For example, central government departments' or local governments' plans for changing the heating systems in their properties, or retrofitting their lighting for energy-efficient alternatives, could be grouped together. Such arrangements need not exclude the private sector, and the Swedish experience is that mixed public and private sector groups can work very effectively together.

Sweden's experience in forming buyer groups has developed over time. Some buyer groups have failed or have been less effective than expected because the personal dynamics of the group did not work well. Experience in Sweden has shown that it is easiest to develop a buyer group when the core members already know each other. The individuals may have the same type of responsibilities, for example some of the Swedish projects have involved individuals from a variety of property-owning backgrounds, thus municipally owned housing companies, housing co-operatives and privately owned organisations have grouped together as they have a common interest. In other parts of Sweden, the groups were formed on the basis of their physical proximity; thus, representatives of municipally owned housing companies in southern Sweden joined with a group of large insurance companies and with a group of individual privately owned householders from outside Stockholm. These buyer groups worked successfully because they had a common interest. In time, such buyer groups could progress to demanding products whose energy efficiency will go beyond those already on the market.

Governments, by acting as a group and therefore as significant bulk buyers, can encourage the technology industry to develop even more efficient products than are currently available on the market. Such a market-pull strategy gives a clear indication to industry that certain product specifications are now required. If the manufacturers meet the new efficiency requirements, they will potentially have a large market for their product. Also, if the manufacturers meet the government's requirements, the unit cost of the product is likely to decrease with large volume sales. In addition, the buyer group may declare a target for improvements to the energy-efficiency levels of specified products which must be met by a set date (perhaps in five years' time), and in the years leading up to this date progressively more stringent values will be specified on an annual basis. To encourage industry to strive for excellence, bonus schemes can be introduced for products which exceed the stated standards.

In some OECD countries, government departments only purchase appliances whose level of energy efficiency is among the top 25% of appliances on the market [*e.g.* in the United States and Switzerland (E2000 label), and the four-star rating scheme in Australia]; in other countries, they purchase products which are at least 10% more efficient than the minimum standard. In these cases the demand for products at the upper end of the market in terms of efficiency will increase and this efficiency standard may well become the norm. However, the disadvantage of making demands which are well within the industry's product range is that this fails to push industry into striving for new levels of excellence, and may indeed discourage further efforts to create super-efficient technologies, because an assured market already exists for current products.

VI. CONCLUSIONS

Climate-friendly technologies offer governments the technological options for reducing their energy use and CO_2 emissions. Reducing energy use in government buildings and vehicles is part of many national programmes for meeting international environmental commitments. Government programmes to enhance the markets for climate-friendly technologies are one element towards achieving their environmental objective of limiting CO_2 emissions. In addition, as one strand of a market enhancement programme for the technology industry, government purchasing programmes can play an important part.

Government activities to encourage the wider dissemination of climate-friendly technologies through its purchasing programmes are important at different stages of a technology's life: to encourage the development of climate-friendly technologies; to stimulate adoption of the technologies through demonstration programmes; to provide the incentives for their uptake in the private sector; and to provide a boost to the technology market through large-volume purchases.

Governments can encourage the development of climate-friendly technologies. For example, markets can be driven by national and international activities to promote super-efficient technologies. The competitive mechanism assures manufacturers of a guaranteed market for the products from among the buyer group members, and so industry has responded to this challenge by developing products to meet the demand. Even manufacturers who have not won the prize have continued to market new, highly efficient products which were originally designed to enter the competition.

In the case of well-established technologies, governments have an important role in pushing the technology manufacturers to refine the product to meet more stringent energy and environmental performance standards. In Switzerland, Australia and the United States, government agencies are required to buy products which fulfil the requirements of the national energy labelling scheme. Energy labels play an important role in enhancing the market for climate-friendly technologies, but only if the demand for products with the energy label is great enough to encourage the industry to respond. Energy labels are also a useful tool for government purchasers, as energy-efficient products are easily identified for their own purchasing purposes.

For some climate-friendly technologies, there is a real need for governments to adopt a technology and give it a high-profile demonstration platform. Demonstration of technologies in action has been found to be a persuasive tool for influencing purchasers' technology decisions. Governments are in a prime position to use their own facilities to demonstrate climate-friendly technologies in operation, and to encourage replication in other institutions and the private sector.

Some technologies need governments to provide the incentive for the technologies to be adopted market-wide. In the case of alternative-fuel vehicles, for example, enhancing their market depends largely on the infrastructure being in place and the price being right. The ease with which conventional vehicles may be converted to use alternative fuels, the availability of electric vehicles, the extent of the infrastructure for repowering the vehicles, and the ability to drive for acceptably long periods of time between repowering stops, are critical factors for the development of this market. Governments can play a role in raising awareness of the technologies by using the vehicles in their own facilities, but unless these other factors are met there will be little progress.

Governments can also give a boost to a technology by the volume of its purchases. As major purchasers in the national economy, there is great potential for governments to direct their purchases towards climate-friendly technologies and to have a positive effect on the technology market. As one of the most significant barriers to the deployment of climate-friendly technologies is their capital cost, mechanisms such as bulk purchasing are important for achieving capital cost savings on the part of the purchaser, while at the same time providing some market security to the industry. This will enable manufacturers to mass produce their product, thus allowing economies in the production costs which will in turn benefit government purchases in the form of lower capital costs. An integrated approach is needed across governments – central and local – which combines the goal of meeting environmental objectives with the goal of enhancing the markets for climate-friendly technologies. Until these are approached as interconnecting issues, a broad range of opportunities will be lost for simultaneously meeting both objectives.

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TECHNOLOGY CO-OPERATION FOR SUSTAINABLE DEVELOPMENT

Table of contents

This article was written by Andrew Dearing of the World Business Council for Sustainable Development (WBCSD).

I. INTRODUCTION

Solving critical environmental problems at the same time as achieving equitable economic growth and social progress is a tremendous challenge everywhere. Innovation – in its broadest sense – will remain an essential part of any solution. Technology supports and enables this innovation by improving economic performance while also permitting cleaner production and reduced resource consumption. Better technology will not be sufficient by itself, but innovation is unlikely to happen without it.

However, before people can gain the opportunities that technology offers, they have to know what is possible and what stands in the way of progress. They also have to be able and willing to take action, and they have to secure sufficient investment. These are formidable barriers for the developing nations to address. They face a vicious cycle when inward investment is influenced by perceived high risk, limited resources and small markets. Such economies may have little choice but to adopt uncompetitive approaches, yet feel coerced by others into bearing the higher costs of clean development. H*ow can they break out of this cycle*?

Many feel that the solution is to have the developed nations transfer modern technologies to the lesser developed nations as a matter of course. This concept – *technology transfer* – has been discussed since the 1992 Rio Summit as a way to help developing economies "leap frog" over approaches that are less effective from an environmental or developmental perspective. Some of the G77 countries continue to affirm a belief in technology transfer as a commitment, not as a commercial undertaking. Unfortunately, the high expectations for this approach have not been met.

Perhaps another approach is needed. Rather than looking at technology as a material good to be given or withheld, we should consider how to achieve maximum value from adapting and applying it. Then, we need to understand what are the significant barriers to the flow of capital investment in order to find better ways to overcome these barriers. The aim has to be to turn the vicious cycle into a virtuous cycle of success for everyone.

It makes no sense for nations to repeat others' failures during the industrialisation process. But there is no point in providing solutions that cannot be used, or doing so in ways that discourage further effort. Technology is a hard tool to use well and to adapt to solve the local problem. One of the best ways to encourage this to happen is to reward those that acquire and apply the necessary competence.

The World Business Council for Sustainable Development (WBCSD) believes that an effective market system can provide the best way to diffuse technology by fostering committed private sector investment and rewarding risk-taking. Approaches that are intrinsic to the way businesses work with their partners in the public and private sectors also help secure the most important assets – skills and knowledge – needed to make better use of technology in the future. This is *technology co-operation*.

However, progress clearly needs accelerating, and today's markets are not as effective as they might be. Some newly industrialised countries have experienced spectacular growth, but incomes in many developing countries are below the levels reached in the 1960s and 1970s. Trade barriers continue to restrict competition. And there is a growing sense that urgent environmental and resource problems – access to water, the provision of adequate food supplies, disease control in the face of increasing drug resistance, climate change – require a more global perspective and a more flexible response than is presently happening.

Successful solutions will improve nations' capacity to attract investment, and increase their ability to apply technology in support of their own sustainable development. Governments, the private sector and civil society each contribute to achieving success in ways that are consistent with broader economic trends. This article looks at some of the factors that can underpin this success.

II. GLOBALISATION AND TECHNOLOGY

Three related trends – liberalisation, globalisation and technology – are transforming the economic rules of the game. The benefits of competitive markets over monopolies have become so clear that most nations are implementing reforms that liberalise their markets in ways that are consistent with local political agendas and their state of development.

At the same time, a new wave of "smart" (*e.g.* information, communication and biological) technologies has matured rapidly. These create tremendous opportunities for environmentally sound development and for a shift towards *knowledge-based economies*. After the first Industrial Revolution, competitive advantage came from access to physical resources. The new revolution is based on ideas, information and management skills, leading to smarter use of natural resources and industrial capacity.

Better communication also means that people everywhere are distinguished less by their awareness of what is possible than by their ability to realise these possibilities. Globalisation is driven by the fact that "best practice" can be shared and information made available instantly around the globe. Values change in the process. People can see that political and commercial inefficiencies remain endemic in developed as well as developing nations. They can also see that financial markets can respond ruthlessly and in ways that damage less robust economies.

In combination, these trends have changed the balance of roles of government, businesses and civil society. Understanding how their responsibilities have changed, and adapting to these changes, are major challenges. Governments have lost some of their freedom to act independently, so are looking for new ways to work together and to challenge the performance of the private sector. Companies are held more and more accountable for their actions, while also having to focus more attention on their specific commercial and technical competencies and on the performance of their investments.

The three trends offer all nations (developing and developed) the prospect of new ways forward for their economies, but they also create new hurdles to overcome. One of the opportunities is to find new ways to compete within the global economy. A corresponding hurdle is that people will need more know-how to be successful. This know-how involves two components: *i*) *explicit* skills to assess the problem and use the available tools; and *ii*) *tacit* skills to bring this knowledge together in ways that safely and effectively solve the problem. Each must be kept up-to-date by *application* based on *local experience* – in other words, they must be constantly *relearned*. The OECD recently estimated that the average half-life of worker skills has shortened to three and a half years.

All nations and organisations will depend upon these skills – their *knowledge capital* – for success in the 21st century. Like other assets, knowledge capital will have competitive commercial value. Unlike physical assets, it is possible for many to possess this capital simultaneously and to use it co-operatively to build better solutions.

One way of describing economies is in terms of pipelines from raw materials to products. From this perspective, sustainable development can be viewed in terms of developing the capacity to meet customer needs for products and services while ensuring that this is done with least environmental impact. An alternative is to view societies as networks of activities. The utility of this approach is that it emphasises the importance of being part of the network in order to learn and acquire benefit from what is happening elsewhere.

From this perspective, addressing sustainable development depends on strengthening the connections within the networks. These connections reinforce people's awareness of their shared and unique values and their understanding of how these values can be transformed into action. Enterprises, governmental and non-governmental organisations, universities and civil society all form part of such networks. A consequence of globalisation is that the networks extend well beyond national borders.

The resources and technical skills that multinational companies deploy will remain an important part of these networks and essential to all nations' sustainable development. However, the role of these firms changes as networks evolve. The contributions made by small and medium-sized enterprises in local communities will become increasingly important as these economies develop. Such enterprises provide the means to tailor solutions to suit local requirements and to deploy local skills flexibly to achieve competitive value in the global market.

Globalisation and the emergence of new technologies are unavoidable trends, and we all have to find better ways to turn these to advantage in addressing sustainable development. Vibrant markets can accommodate and enhance the transition towards knowledge-rich societies. In turn, greater knowledge capital can enhance developing countries' ability to address sustainable development within the global economy by increasing their freedom of choice and ability to find competitive niches. The trends accompanying globalisation reinforce the importance of effective technology co-operation as a process that can involve everyone and benefit everyone. They also reinforce the need to get the framework conditions right within a highly competitive yet rapidly changing world.

III. ENHANCING APPROPRIATE TECHNOLOGY DIFFUSION

Technology by itself has no value: its value comes from beneficial use. The technology required to handle a given problem often exists, although it may need adapting to suit local needs and local budgets. More difficult is to determine how best to use technology when inappropriate choices can be damaging. This is a particularly important requirement when the objective is to balance economic, environmental and social developments taking place on different time scales with varying degrees of uncertainty.

The first requirement is to wish to improve the existing situation by encouraging the experimentation that will make that possible. Current approaches may seem "good enough" but further improvements – more cost-effective approaches, greater eco-efficiency – are usually possible. National and international policies that establish vision, encourage experimentation through competition and reward achievement are more likely to secure these gains than policies that are punitive or proscriptive. This is one reason why trade barriers are damaging – they remove an incentive to find better approaches.

Those that have developed better approaches (for example through their research and development) depend on appropriate protection of their intellectual property rights to make a return on this investment. Companies are unwilling to place valuable assets at risk unless their rights are clearly identified and properly enforced. This protection does not need to be open-ended, and there is a case to be made for encouraging more rapid diffusion of environmental technologies, for example by widespread licensing. There is also a case for re-examining the balance between the ways societies protect explicit and tacit knowledge, to deal with the shift towards more global, knowledge-based economies at a time when many developing nations have no strong history of intellectual asset protection.

Sometimes we do not know which is the best technical approach to deal with a particular objective. What actually is the best way to help farmers move more quickly from the subsistence level? Provide appropriate energy infrastructures in the emerging economies? Address climate change? achieve sustainable urban and transport designs? Protect vulnerable ecosystems without harming economic development? In each case, inappropriate decisions may have long-term consequences.

Dealing with such uncertainty requires flexible public policies. Usually, it is more effective to set these policies in terms of objectives and to reward progress towards objectives, rather than to mandate the approach. However well intentioned, technology standards risk locking society into inappropriate, and probably uneconomic, ways of working.

Technologies used within capital stock are most likely to be fit for purpose at the moment of design. Such stock can have a long lifetime (Table 1), which constrains future choice for an extended period. This emphasises the need to obtain good advice and make effective choices at the point of design and construction. Already long lifetimes are further extended when "perverse" subsidies prolong unsuitable and obsolete approaches.

Table 1. **Average lifetime of capital stock**

Capital stock	Average lifetime
Electrical appliances	5-20 years
Residential heating and cooling	10-20 years
Cars, trucks, buses	10-25 years
Commercial heating and cooling	10-30 years
Industrial production facilities	10-40 years
Power plant, electricity transmission	30-50 years
Transport and urban infrastructures	40-200 years

People place different values on the use of technology. They recognise that introducing technologies presents risks as well as benefits, judge for themselves whether the benefits justify taking these risks, and so need a transparent and well-informed basis for making these judgements. The accompanying ethical issues are perhaps greatest when people make different assessments of risks, values and benefits from country to country and between applications.

In some situations, the consequences of uncertainty may be great enough to justify taking a precautionary approach that will limit the adverse impact of mistakes. However, since this also means spending money to keep options open as long as possible, nations and firms may feel they are being asked to incur costs they cannot afford. Furthermore, the precautionary principle is not yet fully reflected in treaties such as those governing international trade, even among developed nations. This may reflect scepticism that unsubstantiated safety risks are being used to justify protectionism or concern that becoming over-cautious will lead to paralysis. For these reasons, precautionary approaches are only likely to be successful when backed up by more effective international co-operation.

Agricultural biotechnology is a case in point. Requirements differ between temperate and equatorial countries and the step of moving beyond subsistence farming is often hampered by very straightforward cultural problems, rather than by lack of advanced technology. However, there are some hurdles (for example, providing safe and effective pest control) that can best be handled using newer technologies. Realising such opportunities requires the means to address universal aspects of bio-safety, which many developing nations are not yet equipped to do. They will require international help if they are to make progress, which in turn will require a supportive public mood for whatever approach is taken.

These points illustrate some of the issues triggered by new technology. The extent to which developments will contribute to global sustainable development will depend upon how well governments, companies and the international community are able to deal with these tensions. Approaches based upon "sound science" are unlikely to be adequate, even if the public benefits may seem clear-cut.

This means that effective assurance mechanisms will be important everywhere, to measure progress and to demonstrate that the public's expectations of safety and ethical performance are being enforced consistently in both the public and private sectors. When a government has different standards for different players (for example, private companies and the public sector), it risks destroying confidence in its policies and encouraging people to find ways round the standards.

Companies find themselves facing demands for higher levels of performance and accompanying assurance mechanisms in all aspects of their businesses. Aspects of their response fall under the heading of *corporate social responsibility.* In turn, this increases both the value and the need to apply high standards in terms of technology management, environmental performance, staff training and working practices wherever a company operates and throughout its supply chain. Sometimes, the firm's best approach will be to use internationally agreed standards of quality and environmental performance wherever it operates. In such situations, the firm can also assist its partners to reach the same standards. In other situations, where the best approach is not yet known, early standardisation will be inappropriate.

People need more than just technical skills before they can use technology fully and effectively. At least as important are the skills to understand customer requirements, to manage intellectual property and to find ways to overcome hurdles such as high capital costs and existing asset bases. These multi-disciplinary skills are in short supply everywhere and are unlikely to become available in countries that do not encourage the mobility of human capital across their national borders.

This is a particular issue for small and medium-sized enterprises that play central roles within all economies, are flexible in their approach and are key parts of the engine of innovation and future growth. Many of these firms have weak managerial skills and limited technical awareness and lack the resources to remedy the situation themselves. Governments have key roles to play here. They can help SMEs by disseminating information about available technologies, set up business support groups within the local community and provide training – for example, through the university system – to demonstrate successful approaches and good managerial practices.

Finally, there is no clear separation between the contributions made by the public and private sectors in the generation of scientific knowledge and the use and adaptation of technology. Both approaches are necessary and have other benefits in addition to the creation of knowledge and tools. In OECD countries, an increasing proportion of R&D is being funded by the private sector, whereas in other nations, the reverse has happened. However, it is generally a mistake for a developing nation to concentrate too much effort on more fundamental R&D (for example, within its universities) until its economy reaches a stage at which it can use the results that will be produced.

Instead, efforts can be focused on adapting technology to suit local requirements, so enabling the economy to make better technology choices. However, there are wide differences in patterns of technology expenditure among nations. For example, Korea typically spends three times as much on adaptation as on original purchase, whereas China only spends one-fifth as much.

IV. TECHNOLOGY INVESTMENT AND RISK MANAGEMENT

Sustainable economic growth and technology diffusion require investment as well as know-how. Investment spreads most easily towards visible projects that offer adequate financial returns and low risks. However, the fact that a project is potentially attractive does not mean that it will actually draw investment. There will also be other, socially important projects that are inherently uncommercial. Obtaining maximum productive investment requires finding approaches that maximise project visibility while minimising the risks *perceived by the investor.*

Project risk has many dimensions: location, choice of partners, availability of suitable technology and means of finance. The market may be too small, the workforce insufficiently skilled, the government unstable, or (for a multinational) there may be too stringent restrictions on repatriating profits. Only some aspects of this risk will be expressed openly and objectively.

It may be helpful to view the situation as an iceberg. What lie above the water are the visible investment opportunities. Little needs to be done to ensure that these will progress to completion. Below the surface, there are a larger number of less-visible projects. Some may be attractive but go unnoticed; others may be essential to the country's development but too risky for the private sector to address. This is a joint challenge for governments, firms and the international community.

Investment funds come from a number of public and private sources to support either short- or long-term requirements and have different advantages and disadvantages (Box 1). Each source of finance and each policy instrument will be most effective within a particular region of the "risk iceberg". We need to find approaches that: *i*) increase the number of low-risk projects visible above the water line; *ii*) reduce the risk and improve the viability of projects "close to the water line"; and *iii*) deal with socially vital yet uncommercial projects below the surface.

Combining different sources of investment and policy instruments to achieve effective diffusion of technology requires careful judgement and co-operation. For example, it is inevitable that investors will prefer stable societies with effective legal frameworks and a lack of conflict and corruption. Achieving these conditions is primarily the responsibility of host governments. Firms can help these governments in their efforts by positive corporate policies, while international organisations can help to build confidence and reinforce stability.

Subsidisation is generally a bad approach to risk management because it tends to reduce market efficiency, perpetuating obsolete approaches or "picking winners" too soon. However, there are situations in which subsidisation may be necessary. For example, early applications of new technologies are often uneconomic. Short-term market stimulation may help redress this, provided the technology is clearly appropriate for its contemplated use. Achieving clarity in the grey area between unjustified subsidisation and necessary market stimulation depends largely on making sure that there are sound objectives, a transparent decision-making process and the means to review progress and change direction if necessary.

Box 1. **Capital flows to non-OECD countries**

Foreign direct investment (FDI) by the private sector funds people, plant and equipment on a long-term basis. The growth in FDI in recent years can be viewed in several ways. For example, it can be seen as both a cause and an effect of globalisation. Alternatively, it is an indication that market-friendly framework conditions are being implemented. Increasing FDI suggests that the receiving economy is seen to offer a long-term environment for investment and that the skills required to make investments successful are actually being put in place. However, such investment can trigger within the recipient country a sense of loss of equity in national assets. FDI is also distributed unevenly across countries.

Official development assistance (ODA) by governments and other agencies includes grants and technical and financial assistance for various purposes to developing countries. ODA is a vital tool for addressing the intractable needs of the poorest nations, but has too often been applied inefficiently. Aid works well at the *micro* level where dedicated skills are also brought to bear to solve specific problems. At the *macro* level, aid is only likely to be successful where the recipient nation is committed to achieving sound economic management. At this level, it seems best to separate decisions about the *granting* and the best ways of *using* aid. Not least, this eliminates one potential source of corruption. It also reduces the risk of creating uncommercial "white elephants"; this can happen when aid finance is treated as a form of capital subsidy or used to provide technologies that are inappropriate for dealing with local requirements. In both the micro and macro situations, well-managed aid will improve capacity, making future investments less risky. In turn, the improved efficiency is likely to increase the likelihood that those giving aid will give more: they will see that their money is actually doing some good.

Loan finance and equity capital serve the same purpose in developing and developed nations. Each is available at a price. The cost of loans depends upon the credit rating of the investment, which in turn depends upon the perceived risk of the project, the company and its situation. Within smaller, less resilient economies, the primary risks are inflation and volatility within the capital, stock and foreign exchange markets. These risks are made worse by (for example) over-exuberant investment. Equity capital offers start-up funds and a means to extend a business without immediate commitment to repay. However, it also entails shareholder supervision and providing an adequate return to the shareholder, either through dividends or through capital growth. It is a mistake to view equity finance as low-cost.

Portfolio investment is not in itself useful to the firm as a way of financing projects. However, by raising confidence in the rating of the company or the market in which it operates, the firm's cost of capital may be reduced. Again, the risk in developing nations is the volatility of this confidence.

This is an area where some of the newer international instruments such as the Kyoto Protocol's (Flexibility) Mechanisms can be helpful. The most appropriate use of instruments – the Clean Development Mechanism and Emissions Trading – seems likely to be one of increasing the visibility of projects close to the water line that also address particular policy goals (in this case carbon reduction). Provided governments agree on the rules, modalities and guidelines, the instruments then serve to reduce overall portfolio risk. It may be most useful to view these mechanisms as *development tools* that tip the balance in favour of investments that are both cost-effective and environmentally sound.

Continuing the "risk iceberg" analogy further, the role of official development assistance (ODA) is to deal with socially vital projects farthest beneath the water line in ways that will build capacity for the future. It is widely recognised that ODA has to become more focused in order to improve its effectiveness. One possibility is through the creative use of international public/private partnerships. The aid is used to underpin the skills and efforts of the local partner, so increasing the likelihood that that partner will be able to complete the project effectively. In turn, this increases the attractiveness of the project for the international investor, who sees a reduced project risk rather than a source of subsidy.

The main message of this section is to focus on risk reduction as a key instrument for technology diffusion. Capital permits investment, technology follows capital; once the perceived rules of the games change so, too, will people's behaviour. Finding better ways to drive this dynamic – for example, by combining different sources of investment and policy instruments to align people's values on both the global and local scales – is a test of co-operative economic leadership.

V. TWO EXAMPLES

The following examples demonstrate creative approaches that will increase the deployment of technologies capable of supporting sustainable development. The first example shows how it is possible to create an attractive and socially responsible investment within an apparently intractable situation. The second shows how international communities can work together to help an emerging economy find the most appropriate energy platforms upon which to base its sustainable development. Both examples can be seen as exercises in risk reduction.

The electricity challenge in South Africa

Of the 8.6 million homes in South Africa, only 2.75 million had access to electricity in 1990. In October 1998, a massive electrification programme, conducted mainly by Eskom, more than doubled the number, bringing electricity to 67% by year-end. Despite this huge effort, it is unlikely that the grid will ever be extended to supply power to the smallest isolated rural communities. The solar home system and support infrastructure concept offers a viable solution in these locations.

A joint venture between Shell and Eskom aims to provide 50 000 homes – many with very little chance of ever being connected to the national grid – with access to electricity for light, television and radio. This venture is described as a blueprint for similar markets around the world, demonstrating the benefits of working closely with other organisations to provide a power solution for customers. The project provides a commercially viable way of tackling a key social issue – electricity for those living in rural communities. At a local level, it will provide considerable opportunities through job creation, education, entertainment and a power supply that is superior in terms of quality, health and safety.

The Solar Home System will cost customers – currently dependent on candles and paraffin – around USD 8 a month, roughly the same as they spend today on less-effective fuels. The system is made up of a solar panel, a charge-controlled battery and a security and metering unit. Solar panels are supplied from the Netherlands. Magnetic cards are used to store the pre-paid power credit that is drawn down as it is used. It is the first time that magnetic card based pre-payment has been used for a solar home system and provides people with the opportunity to install solar power without having to make a large up-front investment in equipment that they might not be able to afford. The monthly charge is stored on a magnetic card that customers can buy from local outlets, which when inserted into the unit will power it for thirty days.

Community-based workers will provide education to customers on understanding solar energy, operational responsibility and the financial commitment involved in signing up for the solar home systems. The joint venture will also provide the infrastructure to market the product in a localised, responsive and flexible network. Regional branch offices will be responsible for the finance, accounting, training on installation, maintenance and marketing. Local, community owned and operated companies will cover marketing, installation and maintenance. Community owned and operated outlets will be the first place for customers to make contact for their system, magnetic cards or any other queries.

Energy technology for China

China's rapid economic growth and development, combined with the country's huge population base has led to a rapid increase in the demand for electrical energy. China is also the world's largest producer and consumer of coal, currently its main energy source. Meeting this demand in a way that does not further exacerbate already severe environmental damage will remain a challenge for Chinese decision makers and scientists in coming years.

The Energy and Global Change Department of ABB Corporate Research, in conjunction with the Alliance for Global Sustainability (AGS), world-renowned universities and Chinese institutions, has initiated a two-year programme to investigate energy technology and emissions in the electrical power sector in China. Developing a sustainable energy supply for China is an essential part of a global strategy to promote development while mitigating environmental pollution and the potentially disastrous effect of greenhouse gas emissions.

The objective of this programme is to develop a globally applicable methodology for analysing the true impact of electric power generation, taking energy technologies and their environmental impact into account and using China as a case study. In order to limit the scope of the study, one region of China was selected. Shandong Province (which has a population of around 90 million) was chosen because of its independent grid and diversified energy supply. However, the methodology needs to be sufficiently general in design to be applicable to other provinces in China and other countries worldwide.

To achieve this aim, the CETP hopes to break new ground in effective co-operation between industry and academic bodies and between institutions in Europe, the United States and China. A steering committee is responsible for the realisation of the CETP. Its members are representatives of the World Business Council for Sustainable Development and the China Council, along with representatives of ABB and the AGS. The Chinese partners, being pivotal stakeholders and the main data providers, have a decisive role to play in the development of the programme. The tool to be developed will encompass data collection and database development, demand forecasting, energy and economy modelling, electric sector simulation, life cycle assessment, environmental impact assessment, risk assessment, integration analysis and decision support. The system will be optimised for key parameters (*e.g.* cost or emissions of carbon dioxide) and will also examine the trade-offs that must occur as a consequence of different preferences, including technology choices.

VI. CONCLUSIONS

Sustainable economic growth requires continued innovation to achieve a better quality of life for everyone today and for generations to come. Technology is one of the key drivers of that innovation. However, to gain the opportunities that technology offers for combined economic, environmental and social progress, people have to know what is possible and what stands in the way of progress. They also have to be able and willing to take action, and they have to secure sufficient investment. These are formidable barriers for the developing nations to address. They face a vicious cycle when inward investment is influenced by perceived high risk, limited resources and small markets.

This article has examined ways in which the international private sector contributes to overcoming these barriers and how that contribution might be enhanced. Since private investments focus on commercially attractive projects with acceptably low risks, a priority for all stakeholders is to find ways to increase the visibility and reduce the risk of the desired investments, increase the level of competence to use technology effectively and find ways to reduce uncertainty. Some suggestions are made, illustrated by examples, of how creative private and public sector partnerships and imaginative use of international policy instruments can help achieve these objectives.

Some basic conditions for achieving progress include the following:

– Economies built around stable societies with effective legal frameworks and a lack of conflict and corruption.

– Availability of a sufficient number of economically attractive projects that require the technologies of interest.

– The means to obtain or develop the human skills required to address these projects.

Correspondingly, people have to share the belief that adoption of these technologies will help make their lives better. This means that:

– People need to be prepared, through their education, to understand the risks and benefits offered by modern technologies.

– They must define, through the laws and other framework conditions provided by their governments, the sorts of choices they wish to foster and encourage within the market.

– Adequate assurance mechanisms must exist to check that progress is in line with their expectations.

Although addressing these is primarily the responsibility of governments, according to the wishes of their citizens, the international private sector also contributes through its long-term presence within an effective market system. This is both a matter of good business sense and also increasingly seen as part of a firm's corporate social responsibility. In the process, the private sector makes a substantial contribution to technology diffusion through the investments it makes and the skills it helps develop. The main task for aid agencies is to address essential yet intractable problems in the poorest nations. This task should be linked to a commitment by host governments to put in place policies that help create the stable societies needed to secure future investment and support their sustainable development by improving human and material capacity.

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CORPORATE RESPONSIBILITY AND SUSTAINABLE DEVELOPMENT

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This article was written by Voula Mega of the OECD's Territorial Development Service.

I. INTRODUCTION

The concept of sustainable development is concerned with the quality of economic development as well as its speed or level. After the Rio Earth Summit in 1992, many governments made sustainable development a national priority in policy making. Some parts of industry have been following suit. Agenda 21 (Article 30) states that environmental management should be among the highest corporate priorities. As the debate shifts from environmental protection to the broader concept of sustainable development, some firms are adopting this concept as a central corporate value. However, sustainable development is an objective far more complex than environmental protection. And making "gold out of green" can be a costly endeavour and encounter numerous financial, social and even governmental obstacles along the way (WBCSD, 1997).

A main aim of the sustainable development approach is to reconcile social policy objectives and the diverging interests of the private sector (UNEP, 1998*a*). The most enlightened firms have aimed to provide high-quality products and services with adequate returns to shareholders while maintaining a satisfying work environment for employees. With advancing globalisation, the growing importance of corporate governance (OECD, 1999*b*), the emergence of more "aware' consumers and the rising influence of pressure groups, business has to satisfy an increasing number of stakeholders. These include all those affected by their products and services in an expanding geographic area. National, regional and local authorities, employers' and employees' organisations, customers' and citizens' organisations are placing more demands on enterprises that go beyond their basic function of producing goods and services.

Environmental performance is coming to be recognised by government, industry and the social partners as an integral part of the overall management objectives of a firm. For environmental policies to be effectively implemented and global commitments to be successfully met, the environmental performance of a greater number of enterprises will need to be upgraded. However, this is a necessary but not sufficient precondition for moving towards sustainable development, which will require the integration of socio-environmental objectives into overall business objectives. Governments will need to put into place the appropriate policy frameworks, infrastructure and mechanisms for the development and diffusion of reliable information that makes environmental costs and benefits more transparent and raises the awareness of consumers. In this way, consumers and the community at large can encourage business to be active partners in sustainable development and to realise net benefits.

This article discusses various actions being taken by corporations and businesses in response to growing demands for enhanced *corporate social responsibility* (WBCSD, 1999). This includes a growing number of corporate codes of conduct and principles at the regional, national and international levels and for various sectors and industrial groups and examines their potential in reinforcing the momentum towards sustainability.

II. DRIVERS OF CORPORATE SUSTAINABILITY

Environmental legislation and regulations are significant sources of pressure on business for improved environmental performance. They are powerful drivers of corporate behaviour, together with business values as well as cost and competitiveness concerns. Management options for improving environmental performance in industry include pollution-control and waste-management techniques, the introduction of clean technologies and cleaner production, alternative choices for raw materials and energy use, education and training of management and staff, and the conduct of environmental audits. The achievement of sustainability objectives requires awareness raising, training of managers and staff, technical and social innovations and technology transfer and development of new infrastructure and services.

Competitive and cost advantages have also emerged as drivers of corporate action in the environment area. Pollution and waste indicate inefficient and unproductive processes. Many firms have become more aware of the importance of transforming idle company assets into revenue generators. In life cycle approaches, waste is viewed as a potential resource. Waste from one company may be a raw material for another sector, increasing the productivity of both activities and of the economy as a whole. Widening the sustainability focus to embrace cost savings and profit making through waste minimisation and commercialisation, management efficiency and the linking of the environment with health and safety and economic policies has high potential for mobilising business. For example, *eco-design* – design for the environment and the economy – designates a practice by which environmental considerations are integrated into product and process engineering and marketing procedures. Eco-companies aim to reduce the impact of products in all of their life cycle stages and achieve an eco-balance between quality and quantity while realising cost savings and efficiency gains.

Improving eco-efficiency – the efficiency with which environmental resources are used to meet human needs – is one route enabling industry to decouple pollutant release and resource use from economic activity. The Business Council for

Sustainable Development (later the World Business Council for Sustainable Development or WBCSD) adopted eco-efficiency as a business concept in 1992 in its report to the Rio Earth Summit. It stated that eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the Earth's estimated carrying capacity. The WBCSD has pioneered a business strategy of "doing more value with less impact" and described eco-efficiency as creating an essential bridge between the macro-level concept of "sustainable development" and the micro-level concept of "corporate behaviour" (WBCSD, 1997).

Studies by the OECD suggest that factor-10 resource efficiency improvements are both necessary and possible within the next 30 years (OECD, 1998). The WBCSD criteria for eco-efficiency include the minimisation of the material, energy and service intensity of goods and services; the minimisation of waste and toxic releases; the enhancement of the materials life cycle; and the maximisation of the use of renewable resources. Different corporations have attempted to develop indicators and targets for achieving eco-efficiency (*e.g.* Eco-Compass of Dow/Europe); make fundamental changes to production processes (*e.g.* "waste reduction always gains"); develop product innovations (*e.g.* green television, paper-free offices); change producer-consumer relationships (*e.g.* Xerox's *successful asset recovery*); and implement extended producer responsibility (EPR) concepts (*e.g.* the car industry).

Clusters of industrial excellence are essential to promoting shared responsibility, common objectives and new attitudes in the private sector. Such clusters often forge strong links between research and production, universities or higher education and industry, as is the case of the Internal Environmental Care System in the Netherlands. In Ireland, the Clean Technology Centre, established in 1991 as a partnership venture among the Cork Regional Technical College and ten leading companies in the chemical and pharmaceutical industry, is regarded as a pole of eco-innovation. The CTC aims at promoting waste minimisation techniques and greater use of clean technologies and cleaner production. The College addressed the concern for the environment and the need to produce graduates with the appropriate skills for industry; industry improved access to information and skills; and the community established confidence in environmental management in the region, coupled with helping enterprises to stay in business and attracting new firms.

Active citizen participation is a *sine qua non* condition of sustainable development and many companies are responding to more widespread public concern about the environment by greening their corporate image. Green consumers may call for companies to design and demonstrate their contribution to sustainable development. Media have the potential to increase public awareness in favour of sustainable development and create new communication channels between scientists, politicians, businesses and the public. They can exert a strong pressure on business to improve their performance and may indirectly reward and penalise good and bad practice, respectively. However, the media can also spread misinformation in certain cases. Also needed are frameworks and institutions that can provide productive linkages between science and improved information, on the one hand, and media and consumer attention, on the other.

Corporate image and brand name reputation are thus becoming more powerful drivers of corporate sustainability. In many countries, pressure groups and the media can create a climate of trust surrounding sustainable businesses (UNEP, 1998*c*). At the other end of the spectrum, corporations without a declared attitude of commitment to sustainable development may face consumer boycotts, a failure to attract investors and employees and obstacles in raising finance and insurance. Taking the initiative towards sustainable development may be a pre-emptive strike by corporations to get an early start in complying with environmental regulations as well as to improve their image with a certain segment of the public.

III. OBSTACLES TO CORPORATE SUSTAINABILITY

The main obstacles to corporate progress towards sustainable development are linked to market, governmental and systemic failures. Market failures stem, above all, from prices for resources and other inputs which exclude externalities (*e.g.* the full cost to society of a reduction in the availability of clean air or water). Prices should better reflect the full environment-related costs and benefits to society of various activities, and market forces should be brought into play where they do not now exist. In order to improve pricing mechanisms to achieve sustainable development, there is a need for an efficient policy mix including subsidy reform, economic instruments, voluntary agreements, eco-labels and certification schemes as well as reform of regulatory and institutional structures and horizontal support mechanisms (research, education, and technology) (OECD, 1999*a*). International co-operation is also necessary for the reduction of price distortions on a worldwide scale (*e.g.* tax exemptions for energy use in international transport). Government policies may thus compound market failures in not correcting – or further distorting – pricing for environmental goods and services.

Market failures may also reflect asymmetries of information and incentives. Lack of information about sustainability strategies and tactics, best practices and techniques, sustainable use of natural resources, cleaner production, the environmental impact of products and practices or sustainability management tools are often the main causes for management inaction. However, even when this information is available, the passage to awareness, knowledge, planning and action may confront multiple financial and socio-cultural obstacles. The lack of appropriate information networks and linkages between the economic actors in society – particularly public and private – is an example of systemic failures which contribute to under-investment in sustainable development.

Most companies are in receipt of environmental information from a diverse range of sources (employers and trade union organisations, regulatory agencies, public authorities, universities and consultancy firms). Despite this wide range of information sources, or perhaps because of it, enterprises may believe they need more specific information on the integration of environmental and socio-economic objectives and on sustainability management tools. As a first step, they need to rethink their management priorities and approaches in the light of this information and create a corporate culture which features environment-related principles and values. Training for management and staff is of key importance so that the available information leads to awareness and permeates all aspects of corporate decision making.

Environmental awareness, however, may not be useful in the face of vested interests or a lack of financial and technical resources, especially in certain regions and periods of economic recession. Best practices are important in persuading companies that financial resources for sustainable development represent a productive investment and not a costly and unnecessary expenditure. Capacity-building and efficient, effective and equitable resource management are important tools for progressing towards sustainable development at the firm level.

IV. CORPORATE CODES OF CONDUCT

Corporate codes of conduct for sustainable development are guidelines for the ethical behaviour of companies to encourage the incorporation of socio-environmental concerns in their business practices. They are often included in an overall strategy to promote corporate responsibility. Commitment by business to the cause of sustainable development through codes of conduct is a concept being promoted together with human rights, employee rights, community involvement, supplier relations, monitoring and stakeholder rights (WBCSD, 1999; UNEP, 1999). There is a wide range of voluntary codes of conduct developed by national and international governmental bodies and business associations as well as individual corporations. Older codes focus on environmental performance while the newer ones address the more integrated concept of sustainable development. The codes vary greatly, ranging from generic statements and symbolic references to more focused action items and pragmatic milestones. Table 1 gives examples of the various types of corporate codes of conduct concerned with environmental performance and sustainability. In addition to these, environment-related codes have been developed by hundreds of corporate groups and large firms in the OECD countries (Adams, 1999).

Table 1. **Examples of corporate codes of conduct**

	International	National
Government		
All industry	Agenda 21: Chapter 30 OECD Guidelines for MNEs	
Sectoral	UNEP Statement for Financial Institutions UNEP Statement for Insurance Companies	
Private sector		
All industry	ICC Business Charter for Sustainable Development	CERES Principles (United States) Keidanren Environmental Charter (Japan)
Sectoral	ICME Environmental Charter Responsible Care Programme (Chemicals Industry) Green Globe (Tourism Industry)	Minerals Industry Code for Environmental Management (Australia)

A recent OECD inventory of international, national, sectoral and firm-level codes of conduct showed that environmental stewardship (*i.e.* sustainable use of natural resources, waste management, energy conservation, risk reduction, protection of the biosphere) was one of five broadly defined types of behaviour included in these industry codes. Environmental concerns were addressed in more than half of the codes. The other areas were fair business practices, observance of the rule of law, fair employment and labour rights, and corporate citizenship. The inventory defined codes of corporate conduct as voluntary commitments by business entities, putting forth standards and principles for the conduct of their activities. For some codes, adherence is a prerequisite for membership in a business association or for access to recognition of marks. The majority of these codes rely on internal monitoring.

In the environment area, the most prominent international inter-governmental code is Agenda 21, which constitutes a blueprint on sustainable development adopted by governments at the 1992 Earth Summit after extensive consultation with representatives of business and non-governmental organisations (NGOs). It has given a strong impetus to sustainability declarations at all levels. Chapter 30 of Agenda 21 refers to the need for strengthening the role of business and industry and indicates two priority programme areas. Many post-1992 business statements of principles, both individual and collective, national and international, echo the principles and priorities of Agenda 21.

Another example of voluntary codes for business developed at the international inter-governmental level are the OECD *Guidelines for Multinational Enterprises* adopted in 1976 as non-binding instruments of a voluntary nature and presently undergoing their fourth review and revision. The present review process includes a survey of existing codes of conduct in order to distil the main subject areas to be potentially covered by the revised Guidelines. A 1991 UNCTAD Benchmark Survey found that 43% of 170 multinational enterprises, mainly large companies in North America and Europe, had published environmental declarations to guide their international operations; 60% of these companies were found in the extractive industries (UNCTAD, 1993).

Codes developed by inter-governmental organisations for particular sectors include the UNEP S*tatements* on the environment and sustainable development for the finance sector and the insurance industry. The financial sector initiative, revised in 1997 and adopted by more than 100 companies, and the 1995 insurance initiative, signed by 75 companies, are important voluntary developments in the international arena. Both codes include a preamble, general principles of sustainable development, guidelines for environmental management and directions for public awareness and communication. The insurance industry initiative recognises that economic development should be compatible with human welfare and a healthy environment. The code regards sustainable development as a fundamental aspect of sound business management and a strong proactive insurance industry as an important contributor, through its interaction with other economic sectors and consumers. It suggests that sustainable development is best achieved by allowing markets to work within an appropriate framework of cost-efficient regulations and economic instruments. The UNEP Statement for Financial Institutions recognises that sustainable development is the collective responsibility of governments, business and individuals, while both sectors highlight the need to undertake internal periodic environmental reviews (UNEP, 1997*b*).

With regard to codes developed by international industry associations, the International Chamber of Commerce (ICC) B*usiness* C*harter for* S*ustainable* D*evelopment*, launched in 1991 at the Second World Industry Conference on Environmental Management in Rotterdam, is perhaps the most well known. It has been endorsed by more than 2 000 companies in a variety of industrial sectors. The Charter declares that there should be a commonality rather than a conflict between economic development and environmental protection. It consists of 16 generic principles and invites industry to formulate more specific principles (ICC, 1992). The 16 principles refer to environmental management as a corporate priority and call for integrated action and a trajectory of improvement. More specifically, they refer to the need for training of employees, prior assessment of environmental impacts, eco-products and services, customer advice, eco-design and eco-development of facilities and operations, the precautionary approach, emergency preparedness, transfer of technology, and compliance and reporting. The promotion of the adoption of these principles by contractors and suppliers are also among the generic principles of the ICC Charter.

International codes of conduct have also been developed by corporations in particular industrial sectors. These include the chemical industry's *Responsible Care Programme* and the 1993 International Council on Metals and the Environment (ICME) *Environmental Charter*. Interesting initiatives come also from the travel and tourism sector, which now recognises that it can persist only if it develops in a sustainable way. Clean air, clear water and attractive scenery are at the heart of this sector, and new strategies are needed to sustain the resources which attract tourists.

In 1995, the World Tourism Organisation and the Earth Council issued a joint report *Agenda 21 for the Travel and Tourism Industry – Towards Sustainable Development*. It advocates a balance of private initiative, economic instruments and regulation, the translation of global principles into focused local action and new public/private partnerships for constructive leaps forward. The World Travel and Tourism Council's (WTTC) *Green Globe* programme encourages companies to enter a virtuous cycle of continuous improvement and responsibility for sustainable development. Tourism-related codes have been issued by a wide array of organisations such as national tourism boards, regional associations of travel agents and tour operators and environmental organisations (*e.g.* Legambiente). They include diverse declarations such as the *Tourists' Eco-decalogue*, *Green Claims Code*, *Responsible Traveller Guidelines* and other principles for the balanced development of tourism.

At the national level, one industry-wide declaration was issued by the Coalition for Environmentally Responsible Economies (CERES), created in 1989 by 15 major US environmental groups and an array of socially responsible investors and public pension funds. Signatories affirm their responsibility for the future of the Earth and their intention to conduct all aspects of business as responsible stewards of the environment. The declaration includes ten principles and states that the endorsing companies pledge to go voluntarily beyond the requirements of the law and to update their practices constantly in light of advances in science and technology. The principles focus on sustainability management and cover the fields of protection of the biosphere, sustainable use of resources, waste reduction and disposal, energy conservation, risk reduction, safe products and services, environmental restoration, information provision and management commitment (CERES 1998*a*, 1998*b*). Similarly, the Japanese Federation of Economic Organisations (Keidanren) has issued environmental codes of conduct, including *Environmental Guidelines for Japanese Enterprises Operating Abroad*.

An example of a national code developed by a particular industrial sector is the 1996 *Australian Minerals Industry Code for Environmental Management*. The latter was developed after recognition of the need to achieve environmental excellence and to be open and accountable to the community. It initiates a commitment to respond to community concerns through consultation, demonstrated performance and continuous improvement. Signatories to the code are committed to manage activities in a manner consistent with the principles of sustainable development, develop an environmentally responsible culture, consult the community, apply risk-management techniques, integrate environmental management into all operations, set environmental performance targets, ensure that decommissioned sites are rehabilitated and report the company's implementation of the code.

In summary, the main principles which are reflected in most corporate codes of conduct for sustainable behaviour are shown in Box 1.

Box 1. **Main tenets of codes of conduct**

To work towards sustainable development in their programmes and practices, enterprises should:

- Establish worldwide policies for advancing towards sustainable development.
- Integrate financial, economic and social management as a corporate priority.
- Adopt corporate-wide policies and practices to meet integrated socio-economic and environmental objectives.
- Encourage such polices through their supply chains.
- Ensure sustainable use of natural resources and clean production.
- Undertake practices for risk management and accident prevention.
- Adopt life cycle approaches to products and services.
- Promote research, innovation and technology diffusion to advance towards sustainable development.
- Provide education and training for sustainable development both for management and staff.
- Assess their sustainability performance and their overall contribution to sustainable development.
- Engage in external auditing of environmental performance.
- Publish their sustainability reports and foster openness and dialogue with stakeholders.

V. CORPORATE ACCOUNTABILITY AND INFORMATION DISCLOSURE

If codes of conduct constitute declarations of principles, their effectiveness and actual impacts on corporate behaviour are difficult to evaluate. There is a need to examine the way in which the principles are embedded in everyday business practices as well as the gaps between intentions and deeds and the adjustments which are made. Accountability, assessment and public reporting are necessary components of the process of improving industry's sustainability performance. However, the reporting landscape is quite chaotic. The voluntary, non-binding nature of most codes of conduct is related to the absence of independent auditing, although most codes include the necessity for monitoring, assessment and reporting. All organisations working on codes of conduct and information disclosure agree that common indicators and benchmarking are essential for assessing business performance in the environment area.

There are a growing number of companies which have chosen to voluntarily disclose information, both in the form of corporate environmental reports and special chapters in annual corporate reports. However, the picture is far from complete. The CERES coalition reports that there is a gap between the quantity and the quality of the information provided regarding corporate compliance with codes of conduct. In part, this is due to the different formats and metrics each company is using, making comparisons difficult. Customised reports may confuse rather than illuminate stakeholders.

However, there are promising efforts to advance towards harmonisation of public reporting with standardised information and metrics. Worthy initiatives are being taken in the framework of CERES, the European Chemical Industry, the Danish Government Green Accounts programme, the Investor Responsibility Research Centre (IRRC), the German Association for Environmental Management in Banks and Insurance Companies (Vfu), the World Resource Institute, the WBCSD and the non-binding reporting guidelines established by the Netherlands Government. The consulting firm SustainAbility, in collaboration with UNEP, has organised benchmarking surveys with sustainable development as one of five fields in which businesses are rated, together with management practices, input/output inventory, financial practices and partnerships with stakeholders (UNEP, 1999).

Agenda 21 included provisions for environmental reporting, including public disclosure of emissions (UNEP, 1994). Among the codes of conduct, the CERES principles place perhaps the greatest emphasis on monitoring implementation and publicly reporting on progress. Companies commit to annually complete a CERES report and assess opportunities and weaknesses in their environmental management strategies. Such reports help stakeholders and investors get more fully involved in the process of corporate goal-setting and measure companies' adherence to the standards set forth in their statements. The CERES report, a comprehensive standardised report, developed in 1990 and revised annually, has been a leading initiative in fostering corporate environmental accountability through harmonised public disclosure.

Moreover, CERES launched in 1997 the Global Reporting Initiative (GRI), aimed at establishing the foundation for worldwide standardised, voluntary and multi-stakeholder corporate sustainability reporting. The GRI tries to harness the growing interest in reporting through an integrated, balanced and effective process, encompassing multiple views and skills. It is seeking to stimulate worldwide interest in standardised reporting and create an international platform to monitor, advocate and continuously upgrade the process. The GRI attempts to raise sustainability reporting to the level of financial reporting by delivering a steady flow of consistent, comparable and verifiable information, spanning all business sectors and regions. The tools include a set of core metrics applicable to all businesses, sets of sector-specific metrics and a uniform format for reporting this information. While CERES recognises that much remains to be done for the initiative to gain universal acceptance, it suggests that the potential rewards in terms of corporate performance and sustainability are enormous.

VI. CONCLUSIONS

The proliferation of business codes of conduct is a positive feature demonstrating a movement by industry towards contributing effectively to sustainable development. Many enterprises are coming to understand that *business as usual* is no longer an option. However, it is unclear whether the codes of conduct indicate a real commitment to sustainable development beyond a public relations campaign. It is also unknown to what extent the principles are translated into deeds.

Monitoring and assessing the degree of implementation of the codes and their real influence on corporate behaviour is the challenge at present. Monitoring performance, public reporting and benchmarking are essential in order to ascertain the *sustainability value-added* of a company. The development of codes of conduct and information disclosure regarding their implementation are two sides of the same coin. Consistency between intentions and deeds is an important indicator of the reliability of a company and a basis for fostering public dialogue. However, intentions and reports are not always linked; reported information may not always aid in evaluating the "degree of achievement" of the declared objectives and targets. Failures and bad practices are almost never reported, when in fact their reporting could provide insights into the problems and obstacles encountered in complying with such codes.

Finally, the symbolic power of codes of conduct for environmental management and sustainable development should not be underestimated. They constitute a new vocabulary to articulate business ethics and introduce innovative practices and paradigm shifts. These codes may initiate a new momentum towards greater private sector accountability for sustainable development.

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INDUSTRIAL REPORTING OF ENVIRONMENTAL POLLUTANTS

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This article was written by Claudia Fenerol of the OECD's Environment Directorate.

I. INTRODUCTION

In the age of information technology, data and information have an unprecedented importance in the operation of a global economy. The right data can provide government, industry and the public with a tool to determine economic growth, gross domestic product, trade imbalances, financial viability and environmental conditions. The vital importance of data is why more and more governments are developing systems that provide better information about the environment. In order for governments to set and implement environmental policies in the future, governments need to know the state of their national environment and should have a valid and consistent means to measure changes in the environmental status.

To do this, many governments collect data about various releases to different environmental media such as water, air or land.

One tool increasingly used by governments to collect *integrated* data on chemical releases to air, water and soil is a Pollutant Release and Transfer Register (PRTR). A PRTR can provide governments, industry and the public with knowledge about the release and transfer of chemicals and pollutants into the environment.

Worldwide interest in PRTRs has grown at a rapid pace over the past few years. The origins of the international activity on PRTRs are rooted in Chapter 19 of Agenda 21 dealing with the Environmentally Sound Management of Toxic Chemicals, which calls for governments to implement and improve databases on chemicals including inventories of releases. Principle 10 of the Rio Declaration on Environment and Development, also from the 1992 United Nations Conference on Environment and Development (UNCED), states that environmental issues are best handled with the participation of all concerned citizens and that each individual should have appropriate access to information relating to the environment. It says that countries shall facilitate and encourage public awareness and participation by making information widely available.

While governments have traditionally enacted environmental policies in reaction to specific incidents or crises, PRTRs represent a new-generation environmental tool. Governments, industry and the public benefit from having pollutant release data that can help to monitor and evaluate the burden of potentially toxic chemicals of concern. All three groups can use PRTR results to identify potential environmental problems and take action before a critical situation occurs and to improve efficiencies, monitor environmental policy and reduce waste.

Governments need to know the state of their national environment and have a valid and consistent means to measure changes. Data are needed to accomplish this – data which indicate the amounts released and transferred of priority substances, by facility source. If properly designed, a PRTR can provide these key data about the state of the environment. The cumulative result can be the sounder management of the environment.

II. POLLUTANT RELEASE AND TRANSFER REGISTERS

A PRTR is an inventory of pollutants released to air, water and soil as well as wastes transferred offsite for treatment and/or disposal. Facilities releasing one or more of the listed chemicals report periodically – usually annually – as to what was released, how much and to which environmental media.

The main objective of the system is the collection and collation of data on potentially harmful chemicals and waste transfers to all environmental media: air, water and land – by source. It puts in one place data critical to governments for pollution prevention and chemical management. With this information, government can set priorities for reducing, or even eliminating, the most potentially damaging releases.

A PRTR varies depending on a country's needs, conditions, environmental objectives and national priorities. All systems in operation today are based on different goals and objectives; therefore, the design and operation differs – one size or design does not fit all: countries, cultures and conditions all vary. A PRTR adapted to national environmental priorities provides a means to track the generation, release and fate of pollutants over time.

Although PRTRs are designed to be country-specific, there are commonalties between national systems – common characteristics that create a backbone of a system. These include:

- A list of potentially hazardous chemicals for chemical-specific data.
- Multi-media or integrated reporting of releases and transfers, *i.e.* air, water and land.
- Data are reported by source.
- Data are reported on a periodic basis, normally annually.
- Information is made available to the public, normally on a site-by-site basis.

A PRTR is essentially an environmental database of potentially harmful releases to air, water and soil as well as wastes transported to treatment and disposal sites. In addition to reports from stationary or point sources, some PRTR versions include diffuse releases such as those from transport and agriculture.

Another prime characteristic is that data and information are made publicly available. According to Agenda 21, data should be made available to national authorities, international bodies and other interested parties involved in hazard and risk assessment, and to the public to the greatest extent possible, taking into account legitimate claims for confidentiality.

III. COSTS AND BENEFITS OF REPORTING

Establishing an integrated pollutant reporting system can lead to a number of benefits but also involves costs. Governments, the private sector and the public all derive different benefits and uses from such a system. The benefits to be realised depend strongly on the goals, objectives, design and operation of each specific system. Benefits achieved through a PRTR system do, however, involve some costs. As might be expected, costs are higher at the onset of the first reporting cycle because: *i*) the reporting facilities must identify which data to report; *ii*) the government needs to collect, collate, organise and disseminate data; and *iii*) the public must learn how to access outputs of the PRTR system.

The experiences of OECD Member countries with PRTR systems indicate that the primary costs to governments and reporting firms occur during the first and second reporting cycle. After this initial outlay, costs for collecting, reporting and collating the information drop considerably. The lower initial costs for industry could be directly related to the fact that many companies now collect release and transfer data, or similar data, as part of their environmental management programmes. As more and more companies worldwide collect such data to identify wastes and material losses, employees become more educated as to the types of information needed to calculate pollutant releases and transfers, therefore lowering the costs of education and training when a PRTR programme is established.

In addition, recent investigations into costs indicate that they tend to be lower with the implementation of new PRTR systems than when the first national system was inaugurated in the United States in 1988. The reason for this stems from the fact that companies, more often than not, have established an environmental management system and automated the collection of data needed to estimate pollutant releases, thus helping to lower the costs of reporting PRTR data.

The benefits are numerous. PRTR data enable governments to monitor progress on pollution or chemical reduction policies and indicate trends over time. These results can help in identifying the effectiveness of environmental policy and can indicate where adjustments or new policies need to be made. In addition, PRTR data can be used to monitor progress towards targets and commitments to international environmental agreements and conventions and for national environmental strategies or priority plans. In addition, PRTR data can:

- Help pin-point priority candidates to introduce technologies for cleaner production.
- Supply important data for land-use planning activities and for the licensing of potential sources of pollutants.
- Provide indicators for monitoring the environmental performance of industry and governments.
- Provide information about accidental releases, such as spills or emissions from a fire at an industrial facility, and be used to plan for possible emergencies.
- Illustrate the environmental performance of particular government and industry policies.
- Help direct research and development for pollution prevention, recycling, recovery and re-use technologies.

With regard to industry, the collection and reporting of release and transfer data can assist firms to identify material loss which equates to waste, or lost revenue. In turn, a PRTR can stimulate more efficient use of chemical substances, *e.g.* better use and/or recovery of materials and/or other feedstock for production. Increased efficiency means reduced releases and/or transfers over time: this is directly related to increased profits. As regards industry standards, many companies have confirmed that a PRTR can provide a template for environmental reporting under ISO 14 000 and perhaps help to set the basic framework for integrated pollution reporting. The existence of a PRTR could spur reporting facilities to improve internal auditing activities and set corresponding performance measures. Conversely, if industries implement auditing, monitoring and reporting systems in accordance with ISO 14 000, this will greatly facilitate their ability to collect and report PRTR data more cost-effectively.

PRTR outputs can stimulate the private sector, especially small and medium-sized enterprises (SMEs), to develop leak-detection programmes and install "good-housekeeping" procedures. Alternatively, lists of reporting facilities enable technology providers to identify potential customers, *i.e.* supply and demand for cleaner technologies can be matched more rapidly and efficiently. A PRTR can complement active industry programmes such as Responsible Care. Such pollutant release and transfer data can provide a baseline and a method to track trends of pollutants that are deemed of priority concern. This information can be turned into a performance indicator under the code of management practice on pollution prevention.

Collection and collation of PRTR data provides a means for multi-facility operations to compare results among other facilities and within the sector or manufacturing group so as to identify data discrepancies and opportunities for cleaner production. A PRTR offers the private sector the opportunity to lead by example – providing release and transfer information can change the public's image of, and response to, company activities. It allows for workers and the public to be informed about the pollutant releases and transfers into their local environment.

In terms of the benefits to the public, access and dissemination of PRTR data enables informed participation in environmental decision making as well as increased knowledge about their local environmental situation. Often, unforeseen benefits are identified during the operation of a PRTR system. For example, certain aspects of the environmental status of a facility being offered for sale can be estimated from careful analysis of PRTR data; investors are increasingly using PRTR data to help them learn more about the environmental behaviour of a firm they are considering for investment. Under this scenario, facilities become more fully aware of the financial penalty of not being environmentally responsible. Similarly, this awareness could lead to efforts to reduce releases and transfers.

Many of the potential benefits of a PRTR cannot be readily converted into direct monetary or other tangible units. These can include avoiding adverse environmental or human-health risks or promoting commercial activities in developing technologies for cleaner production and products, or stimulating more efficient governmental policies to protect the environment. These actions are quite difficult to quantify, yet should be kept in mind as decisions are made about the positive value of a PRTR system.

IV. DESIGNING A REPORTING SYSTEM

In 1993, the OECD agreed to develop a guidance manual for governments wishing to implement a PRTR system. The basic text for the manual was developed through a series of workshops attended by representatives from governments, industry, and non-governmental organisations. The OECD G*uidance to Governments* M*anual for* PRTRs, which was published in February 1996, sets forth basic principles for developing a PRTR and presents options for implementing an effective system (OECD, 1996*a*). The following section highlights the main aspects of the manual.

Before embarking on the design of a PRTR system, national policy objectives should be reviewed and co-ordinated with local and regional needs. The next step is to develop goals and objectives and to ensure that the system can interact and be compared with other data systems in operation (*e.g.* the geographic information system).

How a PRTR system is designed will determine the benefits to be derived from it. While a PRTR is a national system, the primary principles that create an operating framework are:

- Reporting systems should cover an appropriate number of substances that may be potentially harmful to humans and/or the environment into which they are released or transferred.
- Reporting systems should involve both the public and private sectors as appropriate: a PRTR should include those facilities or activities that might release and/or transfer substances of interest and, if appropriate, diffuse sources.
- Both voluntary and mandatory reporting mechanisms for providing inputs should be considered with a view as how best to meet national goals and objectives.
- The comprehensiveness of any system in helping to meet environmental policy goals should be taken into account, *e.g.* the decision as to whether to include releases from diffuse sources ought to be determined by national conditions and the need for such data.
- Any reporting system should undergo evaluations and be sufficiently flexible to allow it to be modified by governments in response to these evaluations or to the changing needs of affected and interested parties.
- The entire process of establishing the reporting system, its implementation and its operation should be transparent and objective.
- To reduce duplicative reporting, reporting systems should be integrated to the degree practicable with existing information sources such as licences or operating permits.

Key components of PRTR design are given in Box 1. Through the preparation of the OECD *Guidance to Governments Manual for* PRTR*s*, a common set of data elements emerged that are central to the data handling and management function. These elements are the building blocks for a national system. They are of strategic importance for governments seeking to have data that are comparable to other national systems (*e.g.* such as under economic trading zones like NAFTA or the European Union). Of course, governments would naturally add elements as necessary to meet the goals and objectives of their own national PRTR programmes. The common set of data elements is listed in Box 2.

Frequently, small and medium-sized enterprises (SMEs) make up 80-90% of all industrial establishments in a country. For example, in the European Union, over 90% of all firms have fewer than 50 employees. Many SME operations are releasing large amounts of potentially hazardous pollutants into the environment with their daily operations. However, more often than not, SMEs lack access to finance,

Box 1. **PRTR design – key components**

1. Establish clear goals and objectives.
2. Consult with interested and affected parties (stakeholders).
3. Develop a manageable list of potentially hazardous pollutants or chemicals.
4. Define the scope of the system: who must report, to whom, how often, etc.
5. Define what will be reported, *e.g.* data from point and/or diffuse sources, name and co-ordinates of a facility, geographic descriptor of facility, latitude and longitude, etc.
6. Analyse existing reporting requirements to identify how they can be used to attain PRTR objectives.
7. Define how claims of confidential data will be handled.
8. Develop data verification method(s).
9. Define resource needs.
10. Develop a programme review system, *i.e.* facilitate updates and modifications to the system as it grows and advances.
11. Formulate an information dissemination strategy.

technological or managerial know-how. Collecting PRTR data from SME operations is particularly important if a goal of the system is to obtain a true national profile of pollutants of concern.

Countries with operating PRTR systems have developed various methods to handle SMEs at different levels. For example, Canada and the United States both have a reporting threshold based on the size of the company: firms with ten full-time employees or more must report PRTR data. The United Kingdom requires SMEs to report if they fall into a specific process or production category. Noting the special needs of SMEs, some countries have created unique reporting forms to include, for example, only a sub-set of the data elements required to be reported.

The use of thresholds provides governments with a mechanism to define who reports. In practice, thresholds would be the trigger for determining individual reporters. Thresholds can be set by the number of employees, turnover (sales per unit over time), inputs to the facility (amounts processed), amounts manufactured, etc. In setting threshold limits, governments should bear in mind the need to balance the benefits of receiving a report from a SME with the costs to reporters and the authorities. However, if decisions are taken by PRTR designers to limit the number of SME reporters, estimates of releases from SMEs should be encouraged to be included in the PRTR results.

Box 2. **Common set of data elements**

1. Name and address of reporting facility (and mailing address, if different).
2. Latitude and longitude of reporting facility.
3. Activity identifier, *e.g.* SIC or 4-digit ISIC code.
4. Chemical name and identifier: all countries with a PRTR use the C-A-S number.
5. In agreed units: the amount released, the amount transferred and the total amount released and transferred.
6. Period covered by the report.
7. For data claimed as confidential, generic data should be used instead.

V. NATIONAL EXAMPLES

Reporting systems tend to be nationally based and are formulated in accordance with a country's needs, objectives and priorities. Since each system is developed according to national – and sometimes regional and local – goals, no two systems are exactly alike, even if many features may be similar. The following section summarises the main features of reporting systems in the United States, Canada, the United Kingdom, the Netherlands, Ireland, France and the European Union.

In the *United States*, the Toxic Release Inventory (TRI) was created in the wake of the 1984 chemical release disaster in Bhopal, India, and a subsequent major release at a US-based sister plant. The TRI aims to provide citizens with information on potentially hazardous chemicals used and emitted at sites in their area. The TRI's first reporting year was 1988. The central objective is community right to know. Facilities covered by the scheme must currently report each year on releases to air, water and soil and wastes transferred off-site for disposal, treatment, recycling, or energy-recovery as well as pollution-prevention activities.

The TRI has changed considerably since its launch in 1986 under the Emergency Planning and Community Right-to-Know Act. Initially, it was limited to manufacturing plants and covered around 320 chemicals and chemical categories. Reporting requirements did not extend beyond chemical releases and transfers off site. This changed with the adoption of the 1990 Pollution Prevention Act, which established a waste management hierarchy, putting prevention first followed by recycling. Starting with the 1995 reports, the number of chemicals and chemical categories covered by the TRI doubled to around 630. Efforts are currently under-way to promote comparability between the TRI and Canada's National Pollutant Release Inventory, created in 1992, as well as Mexico's *Registro de Emisiones y*

Transferencia de Contaminantes, which is still being developed. The North American Commission for Environmental Co-operation, established under the North American Free Trade Agreement, regularly publishes its *Taking Stock* reports on pollutant releases and transfers in the region.

In the 1990 "Green Plan", *Canada* committed itself to developing a national database for hazardous pollutants being released from industrial and transportation sources. A Multi-stakeholder Advisory Committee representing industry, labour, non-governmental organisations, federal and provincial governments developed a National Pollutant Release Inventory (NPRI) which became operational in 1993. This inventory, which is similar in structure to the US TRI, is intended to serve as a tool for identifying potential environmental problems and for encouraging voluntary reductions of potentially hazardous pollutants. The NPRI is designed to enhance the harmonisation of pollution-reporting requirements across all levels of government for all environmental media.

The inventory list currently includes 246 substances for which facilities are required to submit release and transfer data each year to Environment Canada. Environment Canada encourages reporting facilities to submit data electronically. Thresholds for reporting are facilities with more than ten full-time employees and which manufacture, process or use any of the listed substances in quantities greater than ten tonnes per year. No specific industrial sector is required to report, however, and some activities such as mining, retail sales and agriculture are exempt. Data collected for the NPRI are collated into an annual report, co-ordinating data under specific themes and topics. The report and actual raw data are available electronically through Internet.

Since the 1970s, the *Netherlands* pioneered the use of covenant agreements with specific industrial sectors to reduce pollution emissions. Under these voluntary agreements, industrial sectors agree to reduce emission levels to pre-set levels by a certain target date. In order to ensure that the companies involved are honouring these commitments, the companies' actions are monitored via an emissions register. Using this approach, the Dutch authorities developed two parallel inventory systems; the Individual Emissions Inventory (IEI) and the Collective Emissions Inventory (CEI). The IEI covers emissions to air, water (and, since 1998, waste) from large industrial installations – around 700 or about 30% of large polluting installations. Currently some 170 substances are monitored.

The CEI operates as a more general survey of emissions from other sources. It stores emissions data on smaller companies and data from diffuse emissions from road traffic and other mobile sources, from households and land-use related sources such as agriculture. These two inventories are collated to provide a picture of the pollutant releases in the country.

In 1997, the Dutch Government introduced a draft bill that sought to make the reporting of certain emissions mandatory for an estimated 327 companies using an agreed list of the 130 most polluting substances. The introduction of a mandatory reporting system had four central objectives: *i*) to rationalise reporting; *ii*) to promote the introduction of environmental management systems; *iii*) to increase the accountability of companies; and *iv*) to improve the quality of the data. The detailed application of the mandatory reporting requirements is based on two criteria: identifying those installations which may have adverse effects on the environment (thresholds to be set by Order of Council once the legislation is adopted); and those installations which are granted licences. The Ministry of Environment plans to make the information on emissions available via an Internet site.

In the U*nited* K*ingdom*, the government set out to fulfil a 1997 manifesto pledge to provide the public with accessible environmental information. On 12 May 1999, following a comprehensive two-year consultation exercise with industry and environment groups, the United Kingdom launched a revised and substantially expanded Inventory of Sources and Releases (ISR). The ISR, or "Pollution Inventory" as it is called, contains detailed information on releases from large industrial sites in England and Wales. It is intended to extend the scope of the inventory to smaller industrial processes in the near future and then to cover all sites authorised under the national industrial installation licensing laws.

The Pollution Inventory identifies individual substances and substance groups that may be released to air, water, land or waste. In many respects, it is one of the most modern integrated PRTRs. The data include over 150 different substances from more than 2 000 industrial processes regulated under the EU's Integrated Pollution Prevention and Control (IPPC) regime. The thresholds for reporting are set so as to include 90-95% of all industrial emissions. The data is based on a mixture of continuous end-of-pipe monitoring, emission factors, spot samples and estimates.

In I*reland*, the 1992 Environment Protection Act, as further implemented by Statutory Instrument SI 85, 1994, requires certain industrial facilities to operate under an integrated pollution control (IPC) licence from the Environment Protection Agency (EPA). The facilities requiring such a licence closely mirror the Annex I activities listed in the IPPC Directive. Since the licensing requirements came into force in December 1995, the EPA has granted 371 licences. Rather than using a list of substances, the EPA uses a list of 32 chemical family groups (*e.g.* halogenated solvents) based on EU legislation on dangerous substances and hazardous waste. The emissions data is reported on a multimedia basis, covering emissions to the air and to water and waste. The emissions information is presented so as to account for all raw materials used in the industrial process.

In June 1999, the Japanese Diet passed into law the framework for a PRTR system in Japan. Regulations for the implementation of the PRTR are under development. These regulations will specify the chemicals to be reported, reporting industries, thresholds, etc. The first PRTR report will be published in 2002. It will contain data on releases and transfers made in 2001.

The *French Environment Ministry* currently produces an annual emissions report compiled from information provided by the regional authorities charged with licensing certain installations under the 1976 Act on Classified Installations. Established in 1984, the annual report covers principal emissions to air and water. The Ministry intends to expand the system to cover waste emissions in the near future. Operators of installations producing or handling more than 10 tonnes of listed substances must prepare annual emissions reports. These are then fed into an inventory by the regional authorities. Other operators of installations requiring licensing under the 1976 legislation have to report every four years, although the frequency may depend upon permit requirements at a regional level. This system is not what is considered a PRTR, but it is indicative of a system in place that could be modified to become a PRTR.

As to the *European Union*, representatives from the 15 member states and the European Commission met in September 1999 to discuss the details of a European Pollutant Emissions Register (EPER). The objective of this meeting was to try to reach agreement on a mandatory list of pollutants and a corresponding mandatory list of source sectors from which operators will have to regularly report emissions data. In itself, the reporting of emissions data for each separate environmental medium is nothing new. However, the current discussions seek to go much further: the creation of an integrated EPER will provide policy makers with an effective environmental management tool for crafting future EU environmental policy. It will enable the Commission and member states to monitor emissions reductions throughout Europe and help them to ensure compliance with international obligations on emissions reductions. It will also enable comparisons to be made between industrial sectors and between individual countries.

The Commission will publish an inventory of principal emissions and sources responsible, thereby giving the general public a source of information on emissions that is presently largely unavailable, at least in an integrated format. After some slippage in the timetable, it is expected that 2001 will be the first year for which emissions are reported.

As signatories to the Aarhus Convention, most western European countries have already undertaken to develop emissions registers. Article 5 of the Convention, signed on 24 and 25 June 1998, contains specific provisions on PRTRs requiring, "[e]ach party to (..) take steps to establish progressively, taking into account international processes where appropriate, a coherent, nation-wide system of pollution inventories or registers on a structured, computerised and publicly accessible database compiled through standardised reporting."

In the OECD, a Council Act was approved in 1996 on "Implementing Pollutant Release and Transfer Registers" [C(96)41/FINAL] (OECD, 1996*b*). The recommendation calls for Member countries to take steps to establish, as appropriate, implement and make publicly available a Pollutant Release and Transfer Register (PRTR) using as a basis the principles and information set forth in OECD (1996*a*), OECD *Guidance to Governments Manual for* PRTRs. The strong interest in PRTRs prompted the OECD to embark on an outreach programme to help put the guidance manual into practice and introduce the concept and benefits of a PRTR to non-OECD countries. To accomplish this, the OECD, in conjunction with the United Nations Institute for Training And Research (UNITAR) and the United Nations Environment Programme (UNEP), held three regional PRTR workshops for countries in key economic regions: in Asia, in Prague for representatives of Central and Eastern Europe and the New Independent States of the Former Soviet Union, and in Mexico.

The current programme within the OECD focuses on providing practical tools to Member countries to help them with their efforts to develop or modify a PRTR system.

VI. CONCLUSIONS

Efficient environmental policy requires sufficient knowledge about pollutants being released to air, water and soil as well as transferred off-site for disposal. When only some of this information is available, governments can be left ill-prepared to establish clear and competent programmes. In order to set and operate environmental policies in the future, governments must know the current state of their national environment and have a consistent and valid means to measure changes to the environment. Then, to fully understand pollutant impacts, data are needed concerning the identities of pollutants, the amounts released or transferred, the potential risks involved, and the sources of these substances – in particular the exact locations of these sources. A Pollutant Release and Transfer Register is an information system which meets these criteria by providing essential data about the state of the environment. As such, it can be a vital tool for sounder management of the environment and to augment national and global efforts in the pursuit of sustainable development.

The goal of environmental policy should be to seek to protect humans and the environment from potential risks. This should be done in a cost-effective manner and provide all affected and interested parties with the opportunity to participate in the selection of policy options. A pollutant reporting system can be an effective tool for identifying areas of policy needs and for setting priorities for risk reduction by providing information on the pollution burden, which would otherwise be difficult to obtain. The information can provide new insights into the distribution of pollutants of concern, prompting more precise priority setting and environmental decision making by public sector bodies.

Over the past few years, OECD Environment Ministers have indicated the need for longer-term horizons for planning – developing a better collective sense of the goals for the next ten, 20 or 50 years. Just as important as formulating a longer-term plan is establishing a monitoring programme to indicate progress towards goals. A reporting system is an effective tool for indicating the performance and progress of specific environmental policies and for identifying particular achievements and needs. To accomplish this, data about the releases of certain pollutants need to be drawn together to form a baseline. This data collected over time can be aggregated and then assessed against the baseline. Results can be used to enhance the clarity and transparency of both the pollution situation and progress towards the targets or goals of government policy.

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CONSUMER POLICY AND SUSTAINABLE CONSUMPTION

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This article, which is based on a survey of Delegates to the OECD Committee on Consumer Policy on *Consumer Policy Contributions to the Development of Sustainable Consumption Patterns*, was prepared by Ilkka Cantell, Ministry of Trade and Industry, Finland, and Mats Ericsson, Ministry of Finance, Sweden.

I. INTRODUCTION

There is general agreement that it will require a change in social attitudes and culture to achieve sustainable development objectives, including making progress towards more sustainable consumption. Most people look to governments to provide the leadership necessary to facilitate that change. This could, however, be a difficult task, as government agencies may have neither the knowledge nor the moral authority to determine how best to resolve the problems related to sustainable consumption and effectively encourage a change in the behavioural patterns of the general public. Any attempts to do so will find governments competing for attention with many other opinion-shapers such as the advertising industry, the media, educational institutions and businesses. Still, governments could put greater efforts into providing consumers with information on: *i*) the environmental impacts of their behaviour and product choices; *ii*) the potential environmental benefits of alternative consumption patterns; and *iii*) examples of progress with government and independent actions already undertaken.

Determining the value and benefit of making such information available to consumers to use as they make their purchasing decisions broadly corresponds to the approach undertaken by the OECD Committee on Consumer Policy. OECD work on sustainable consumption and production was initiated in 1993 in line with a Ministerial Council request that the OECD examine the relationship between consumption and production patterns and sustainable development. A number of activities were undertaken in response to this request, including several expert seminars, support for the Ministerial Roundtable on Sustainable Consumption held in Oslo, Norway (February 1995) and the UN Commission on Sustainable Development (UNCSD), and an OECD Workshop on "Sustainable Consumption and Production: Clarifying the Concepts" held in Rosendal, Norway (July 1995).

The Committee on Consumer Policy wished to make a concrete contribution to this debate by outlining what has been done and what could be done to educate consumers about sustainable consumption patterns and encourage them to take some personal responsibility for the environment and resource management while making purchasing decisions. Relevant information would include: studies concerning consumer attitudes toward environmental issues in general; information and educational activities intended to raise consumer awareness and to initiate behaviour change; environmental claims in marketing; the role of the manufacturing and retail industries in providing consumer information and education; eco-labelling; the consumer's role and participation in waste separation and disposal; studies concerning product durability and moves towards a service-based economy; and the environmental aspects of product testing.

The Committee decided to focus on the issues related to the core activities of consumer policy and consumer information. A questionnaire on *Consumer Policy Contributions to the Development of Sustainable Consumption Patterns* was distributed to all OECD Member countries in July 1996. This report summarises the responses to the questionnaire, providing a snapshot view of consumer-related activities in the area of sustainable consumption.

II. CONSUMER AWARENESS OF ENVIRONMENTAL ISSUES

As indicated in previous studies and surveys on this subject (see Bibliography), many consumers already consider environmental issues to be important. However, while consumer knowledge of the environmental effects of consumption has grown, there is still much to be done to further increase and expand the level of knowledge and awareness. Today, shoppers can, for example, make a conscious choice to buy a specific product because it is less environmentally harmful than another, but they often completely ignore other environmental factors related to their purchase, such as the impact of using a private motor vehicle to go shopping, the environmental effects of goods transport, and so on. The environmental impacts of certain products and packaging over the full span of their life cycle can also easily be forgotten as consumers often take only immediate and sometimes minor details into account.

While conceptually many people are willing to assume more responsibility for the environment, in reality they do very little to change their consumption patterns. It should also be noted that a number of outside factors may make it difficult for consumers to change their behaviour, including the lack of information about appropriate choices and inadequate or unavailable recycling programmes.

An increasing number of consumers are concerned and interested in making environmentally sound product choices. Studies indicate a consumer need and desire for environmental information, including general facts about the environment, energy conservation, ecologically responsible consumption, and suggestions as to how a consumer can change his/her buying habits. However, a lack of product information is the most frequently cited obstacle to making more environmentally sound purchases. Many consumers also feel that they are too busy to spend extra time in a grocery shop comparing one product with another to determine which is the best for the environment, while at the same time considering the price, quality and the potential risk of selecting a new, untried product.

Despite these difficulties, many consumers say that they are willing to pay to protect the environment, sort their waste for recycling and shop in an environmentally sound way. As evidence of growing consumer awareness and concern, a study conducted in Canada in February 1997, revealed that 77% of those surveyed answered "yes" when asked whether or not in the last year or two he/she had selected one product over another because of its environmentally friendly packaging, formulation or advertising.

Study results such as these suggest that consumers can be encouraged to buy more eco-labelled products through the use of advertising and media campaigns – in short, through improved marketing. Through the use of the media, consumers could generally be informed that, as they make their purchasing decisions, there are products available that are less harmful to the environment than others, and they could be encouraged to make that choice. The European Union has developed an eco-labelling plan, the Nordic countries share a common system, and a number of other OECD Member countries also have national eco-labelling schemes. Raising consumer awareness and helping to influence consumer behaviour could, in turn, encourage manufacturers to develop products and production methods that can reduce the burden on the environment.

There is still much to be done to increase consumer awareness of eco-labelled products and to promote environmentally sound consumer choices. Although some eco-labelling schemes have quality specifications, consumers may harbour some doubts that eco-labelled products are of equal quality to other products. An environmentally sound detergent that does not clean, does more harm than good by discouraging consumers and may cause them to believe that "eco-labelled" equals "inferior". Manufacturers of ecologically sound products should be encouraged to focus more attention on producing quality goods and on providing consumers with assurances about that quality. Consumers' purchasing decisions can also be influenced by making eco-labelled products more visible and more commonly available in shops.

Similarly, a number of national studies were undertaken in an attempt to understand how best to initiate and maintain recycling programmes. Individual attitudes are critical to the success of an effective and sustained recycling programme. It is important that people are willing to fully participate and contribute to recycling programmes by sorting waste so that the various recycling systems can work practically and efficiently. The studies revealed that the older generation was more environmentally concerned than the young, both in deed and in attitude. Another finding showed that, on average, women could be characterised as more environmentally concerned than men. A number of demographic studies showed that those most likely to fully understand the ramifications and benefits of recycling programmes tended to be younger and middle-aged, better educated, working adults with higher incomes.

Many people seem to think that environmental issues related to packaging and recycling include only waste separation and disposal arrangements. Consumers tend to overlook the fact that the product choices they make when they are shopping and their consumption patterns in general are very central in this respect. Relatively few studies have been conducted to determine how the consideration of environmental impacts can influence purchasing decisions, perhaps indicating that the importance of consumer choice has not been fully recognised. Governments could also work to help influence the choices made by both consumers and businesses through the use of voluntary agreements with industries such as differential taxes that favour green products and penalise those that are harmful to the environment.

III. INFORMING AND EDUCATING CONSUMERS

The OECD countries have undertaken a wide range of consumer information and education campaigns to enhance consumer understanding and knowledge regarding environmentally sound product choices and other behaviour. These campaigns can be put into three general categories: *i*) product choices and use; *ii*) consumption patterns; and *iii*) waste processing (Box 1).

A number of government-sponsored campaigns were developed and launched to help promote environmentally sound *product choices and use*. The Danish campaigns "Recycling or Racing" and "Environment and Washing Clothes" were addressed to schoolchildren. The campaigns were intended to change the way schoolchildren lead their daily lives and to alter their consumption patterns by teaching them to make better environmental choices. A Finnish book entitled "Eco-Buyer" and a related education campaign were addressed to all consumers, as was the "Green Purchasing Network" undertaken in Japan. The book and the two education campaigns were aimed at consumers who want to make environmentally sound purchases but face considerable problems when they try to do so in practice. They were also specifically intended to create greater market demand for environmentally sound goods and services. A Nordic eco-labelling campaign (the Swan label) was introduced to help consumers identify more environmentally sound products.

Additionally, many European Community (EC) countries participated in the European Young Consumer Competition related to the impact of consumer behaviour on the environment. The competition was open to secondary schoolchildren and aimed to encourage them to find ways of taking better care of the Earth's natural resources.

Regarding campaigns to influence *consumption patterns*, the Danish campaign "Consumption and Environment" and the Norwegian edition of a booklet on sustainable consumption, were aimed at teaching schoolchildren how to reduce the

Box 1. **Environmental consumer campaigns**

Austria. Ecological Lifestyle (1996); The Impact of Consumer Behaviour on the Environment, The European Young Consumer Competition (1996).

Canada. Action 21, Information, Education and Assistance Programme (1995); Rescue Mission – Indicators for Action; Consumers and Environment – Industry Canada's Web site Strategies (1997).

Denmark. Recycling and Racing (1994); Environment and Washing Clothes (1995); Local Agenda 21 (1995); Consumption and Environment (1996).

Finland. Eco-Buyer Campaign (1995).

Japan. Green Purchasing Network (1996).

Korea. Consumers' Pledge for Sustainable Consumption, Consumer Organisation.

Mexico. Education for Consumption (1994); Electricity Commission permanent campaign on energy saving; Mexico City permanent campaign on fuel saving.

Norway. Nordic Eco-labelling scheme; Nordic booklet on sustainable consumption made for secondary schools.

Sweden. Nordic Eco-labelling scheme; Good Environmental Choice; Shop-Green week every autumn.

Switzerland. Save Our Planet (1996); National Waste Campaign (1995); Campaign for Nature-like Leisure Gardening (1994).

strain on the environment and encourage them to change attitudes in a way that can contribute to making both private and public consumption environmentally safe. The Austrian campaign "Ecological Lifestyle" targeted all consumers, and was intended to provide additional information on environmental and consumer issues with a special emphasis on energy conservation.

The permanent campaigns "Local Agenda 21" in Denmark and Sweden, "Educating for Consumption" in Mexico, and the one-off "Save Our Planet" in Switzerland are aimed at all consumers. Their goal is to educate citizens, strengthen their environmental awareness and encourage manufacturers to develop products that are less environmentally harmful. "Save Our Planet" was intended to protect the climate and the diversity of species, and to promote sustainable consumption. A similar campaign is being carried out in Canada.

The various *waste processing* campaigns underway were not addressed to any specific consumer groups. The aim of the "National Waste Campaign" in Switzerland was to save both natural resources and money and to inform the public about efficient waste management and separation. Information campaigns on the separation of household waste have also been carried out in Sweden, and Mexico is running a permanent campaign encouraging separation and disposal.

A number of private sector and joint public/private initiatives provide consumers with information on environmental products. For example, the Japanese have established a "Green Purchasing" campaign to protect the environment by raising consumer awareness of the environmental effects of products. Consumers can receive additional environmental information from the "Report on the Environment" and "Plan for Eco-Activity" publications.

The Association of Swiss Recycling Organisations has published a guide outlining the efforts underway by manufacturers and retailers to achieve more sustainable product use. Recycling arrangements have been made for aluminium, glass, paper, board, tinplate cans, bottles and textile products, and co-operative arrangements are primarily conducted between the organisations representing manufacturers and retailers. Similarly, the major Finnish wholesale/retail organisations (Kesko, Tuko, SOK, Tradeka) each have their own environmental programmes for organising recycling and waste disposal.

The manufacturing and retail sectors participate in Nordic eco-labelling work by nominating representatives to hold seats on committees of experts that draft criteria for different product groups. The criteria are then given final approval by the Nordic co-operation body that stipulates the rules for Nordic eco-labelling. The environmental effects of eco-labelling depend largely on the relevance and significance of the criteria applied as well as on the market share and placement of eco-labelled products, which in turn depends on the strength of consumer preference for these products and the responsiveness of producers and suppliers. Thus, in order for eco-labelling to be an effective marketing instrument, the public must be aware of the advantages of eco-labelled products, and manufacturers and retailers should provide consumers with more information about their eco-labelled products. Similar co-operative efforts are in effect in other OECD Member countries, such as the Canadian Environmental Choice programme.

IV. ADVERTISING AND THE ENVIRONMENT

Information about the environmental impact of products is important to consumers and it is crucial that this information be accurate and truthful. Responsibility for ensuring the accuracy of environmental claims varies, however; in some OECD Member countries, the supervision of environmental claims is primarily the responsibility of government authorities. In others, misleading environmental claims are dealt with more often through self-regulatory measures and consumer and marketplace reaction. In the United States, for example, consumer protection is coupled with competition policy under the authority of the US Federal Trade Commission. In Japan, consumer issues are enshrined in legislation with the "Act Against Unjustifiable Premiums and Misleading Representations" and as yet, there are no voluntary guidelines.

Issues relating to environmental claims in marketing have been the focus of much attention in the Nordic countries. Nordic marketing legislation prohibits the use of improper or misleading marketing and manufacturing claims. The primary enforcement bodies in the Nordic countries include the Consumer Ombudsmen and the Market Courts. The Nordic Consumer Ombudsmen have developed common guidelines for the use of advertisers and advertising agencies concerning environmental claims in marketing. Consumer Ombudsmen provide legal advice to enterprises regarding proper marketing, and can prosecute manufacturers and distributors if their marketing has been demonstrated to be illegal or misleading. If a ruling to this effect is issued, it may include a conditional fine (*i.e.* one that will be payable only if the marketing campaign continues in the same form). If a marketing entrepreneur does not agree with a ruling of the Consumer Ombudsman, he can ask for the case to be presented to the Marketing Council, which will then decide if the ruling stands or should be overruled.

In recent years, the Nordic Consumer Ombudsmen have taken action against misleading environmental claims in advertising. The Ombudsmen have noted that in environmental marketing, the truthfulness and relevance of the information provided is very important, particularly in the case of products such as cars, which typically represent a major environmental burden. For example, the term "environmentally friendly" and similar expressions should not be used unless a thorough study has been made of the environmental impact during the entire life span of the product.

In Canada, the Environmentally Sound Packaging Coalition of Canada (ESPPC), a coalition of consumer and environmental organisations, has undertaken a project entitled "Truth in Environmental Labelling and Advertising". The aim has been to help avoid the misleading use of environmental or green labelling and advertising. The major stakeholders in the project were invited to workshops where they discussed and evaluated new government guidelines entitled "Guiding Principles for Environmental Labelling and Advertising". As a result of the workshops, a number of changes were made to the guidelines and a recommendation was issued that the government take a more visible and proactive stance in responding to consumer complaints.

The major regulatory measures available in Canada to combat false environmental claims in advertising are provided by Section 7 of the Consumer Packaging and Labelling Act and by Section 52 of the Competition Act. The primary enforcement bodies for the Act are the Competition Bureau of Industry Canada and Agriculture and Agri-Food Canada.

There have been a number of landmark court cases regarding advertising claims in the environmental area. In 1988, the CRIOC (*Centre de Recherche et d'Information des Organisations de Consommateurs*) in Belgium filed a case against Procter and Gamble, manufacturers of a phosphate-free detergent, because it polluted the environment despite a claim to the contrary. The CRIOC also cited Opel for misleading consumers because the company marketed itself as "environmentally friendly", a claim that was said to be untrue since all cars pollute.

In Denmark, an association of market gardeners had given their products an environmental label on the grounds that they had reduced the use of certain plant sprays. The Consumer Ombudsman insisted that the label, "Green Environment", be removed because, while the products in question had been improved in some respects, they had had not been subjected to an environmental life cycle analysis.

In 1992, the Finnish Market Court ordered General Motors to discontinue the use of the expression "for a cleaner environment" in the marketing of cars, or face a fine of FIM 200 000, unless the claim was set out in detail with enough evidence to support it. The song and pictures used in the commercial were regarded as having an undue influence on consumers.

For a product to be marketed as having an environmental advantage over others, the Norwegian Consumer Ombudsman requires it to be among the best of corresponding products in the market. For example, the Consumer Ombudsman reviewed a case involving the use of the term "environmentally friendly" in the marketing of disposable kitchen towels. The CO ruled in this case that the environmental merit must at all times be judged in relation to the availability of similar articles. If a significant number of these products meet a higher environmental standard, it must be deemed misleading to characterise a product as environmentally friendly. The CO ruled that the product ought to be among the best third of similar products with respect to environmental effects.

In 1991, the Swedish Market Court also prohibited General Motors from using the expression "environmentally friendly" in an advertisement for the Opel Omega. In the same manner as the Belgian CRIOC, the Market Court considered it clearly misleading to use the term "environmentally friendly" in this context.

V. CONSUMERS AND RECYCLING

A variety of systems for recycling and waste disposal exist in different countries that enable consumers to either recycle or sort wastes, or do both. For example, in Switzerland, since 1990, the recovery rate has increased as a result of refuse bag fees, increasing consumer awareness, and an improved infrastructure allowing for separate collection. Recovered materials include glass, paper and board. Earlier, a large proportion of waste was still being processed in incinerators without flue gas scrubbers.

Using a range of incentives, attempts to increase the sorting of waste by the general public have achieved some success in parts of Finland and Sweden. The recycling rate is generally very high for glass bottles, aluminium cans, cardboard and paper. As a result of the deposit-refund system for bottles which makes recycling convenient and cost-effective, the glass bottle recycling rate in Finland and Sweden is now more than 90%. Packaging producers are responsible for packaging even after it has been used, and all waste to be sent for final disposal is sorted into categories on the basis of its suitability for further processing.

In Norway, most municipal waste is deposited into landfill dumps, and the limited amount of land available for dumping has necessitated an increased reliance on recycling. Recovered materials include paper, cardboard, packaging, food waste, bio-waste, glass, tyres, plastics, metals, textiles and waste oil. There is also a system for dealing with hazardous wastes.

In Canada, manufacturers and retail industry have attempted to promote sustainable consumption by reducing the waste associated with the use of their products. Companies are also making some limited efforts to increase the durability of their products (*e.g.* cars). The high-tech industry is seeking to increase the ability to upgrade its products, allowing products to be updated through the use of renewed software rather than replacing hardware.

In many countries, local authorities are responsible for the waste collection service, ensuring the separate collection of glass and paper by providing containers for voluntary disposal of newspapers, cardboard and glass containers. Local authorities have special disposal arrangements for, among other items, garden refuse, bulky waste, oil and chemical wastes. In Austria, for example, municipalities are required to provide or arrange for separate collection of hazardous waste at least twice a year. However, waste collection is not just a service that citizens are entitled to – each individual has a role to play and responsibilities to carry out. The success of such a system depends on consumer participation and, while voluntary consumer co-operation and participation is the most desirable option, it is not always easily achieved. Local authorities could offer a "carrot and stick" approach by invoking the threat of penalties for inadequate participation (*i.e.* imposing extra charges for unsorted waste or the imposition of fines).

The number of waste separation facilities provided by producers is typically too small relative to the population they serve. This leads to a transport burden for individual households, as some consumers may have to use their car to take their wastes to separate disposal points. In addition, many countries find it difficult to arrange for the disposal of hazardous wastes in a way that suits consumers. In Japan, such wastes are collected by licensed operators. A further issue stems from the fact that that more stringent requirements related to waste management inevitably lead to higher costs.

With regard to product life, studies relating to consumer goods indicate that durability has not yet become a prominent issue in consumer policy. Furthermore, little or no information is available in relation to the technical durability of consumer goods. One study revealed that the most effective tool to help consumers extend the service life of home appliances is an instructive and easy-to-use product manual. User-friendly product manuals that take into consideration both information content and lay-out must be developed. A number of government authorities have produced consumer information based on the findings of this study and have urged manufacturers to take account of its results.

For product durability to be perceived as a valuable characteristic and have an impact on purchasing choices, consumers should be provided with reliable information about the durability of the goods they are offered. For this reason, consumer organisations should produce more publications that contain test information and guide users towards consumption patterns that give priority to products with long life spans. However, it is evident that such tests are expensive and time-consuming, and frequent new product launches swiftly render their results out of date.

VI. CONCLUSIONS

Surveys of consumer attitudes show that many consumers recognise the importance of environmental issues and are willing to assume more responsibility for the environment. However, they often believe that their personal contribution to these issues is limited only to waste separation and disposal arrangements, and do not recognise the wider sphere of influence they can have. On a practical level, even willing consumers are often unable to change their behaviour as they may not have access to satisfactory recycling programmes or adequate environmental and product information to help them make educated purchasing and lifestyle decisions.

Manufacturers have an important role to play in affecting consumer choice and encouraging the purchase and use of more environmentally sound products. In addition to providing complete and effective product information and user manuals, manufacturers should be encouraged to focus more attention on producing quality goods and services and, in turn, providing consumers with assurances about that quality. Raising consumer awareness and helping to influence consumer behaviour could serve to encourage more manufacturers to develop products and production methods that can reduce the burden on the environment.

The OECD survey indicated that, in general, consumers are not very well informed on environmental issues and that they need additional and more accurate information to help them make environmentally sound purchasing decisions. Governments, businesses, consumer and environmental organisations should work together to provide consumers with easy access to information and educational materials on environmental issues. Product guidebooks or separate appliance lists would enable consumers to quickly assess and learn about the more ecologically sound products available in the marketplace.

One strategy to improve consumer awareness and encourage consumers to change the ways in which they shop and buy is to arrange more concrete and sectoral education campaigns, such as those found in Finland which concentrate on specific product and service choices rather than on broad consumption patterns. Targeting information can help to improve the effectiveness of environmental and consumer information and education campaigns. Different consumer groups have different needs with respect to environmental information, and their potential to be influenced by information varies. In certain circumstances, consumers can be encouraged to work together to view the environment and sustainable consumption as a community effort. For example, families living in blocks of flats or groups of friends can be encouraged to buy in bulk or to organise the sharing of consumer goods, and several families could use common household appliances.

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