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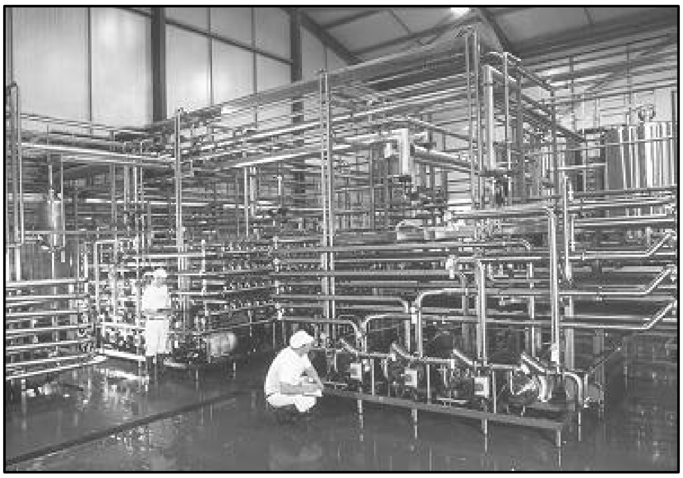
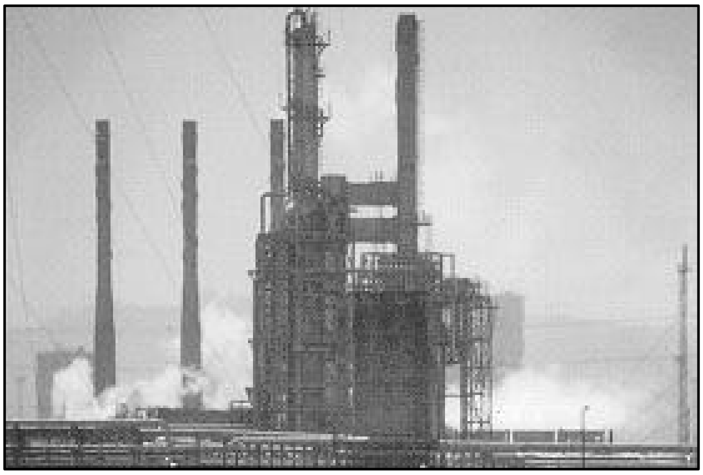


CLEANING UP?

Stimulating Innovation in Environmental Technology



Report No. 136
April 2000

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The Parliamentary Office of Science and Technology was established in 1989, and is an office of Parliament which serves both Houses by providing objective and independent information and analyses on science and technology-related issues.

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Cover Photographs:

Top:	*Use of membrane technology at Joseph Helier Ltd*
Courtesy:	*Environmental Technology Best Practice Programme*
Bottom:	*Petrochemical complex*
Courtesy:	*Environment Agency*

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C O N T E N T S

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1 INTRODUCTION

Over the last 20 years, industry has shown greater acceptance of the need to take account of environmental issues, and build them into the design and operation of business (1). One result has been a growth in what has been called the 'environmental technology and services' (ETS) industry (2). This sector is, however, difficult to define, because it covers such a broad range of products and services (**Table 1.1**) and comprises a disparate grouping of sub-sectors, linked together only to some extent by the fact that the goods and services they provide are aimed at protecting the environment.

TABLE 1.1 THE ENVIRONMENTAL TECHNOLOGY AND SERVICES INDUSTRY

Air pollution control	Water and waste water treatment
Waste management	Contaminated land remediation
Marine pollution control	Environmental monitoring
Environmental services (consultancy)	Energy management
Noise and vibration control	Management of natural resources and soil

Source: (2, 3)

One key sector where environmental concerns have become increasingly important is that of the process industries[1]. Here, efforts are being made to reduce environmental impacts by cutting down the generation of waste products, and two technological approaches have developed. The first is often referred to as the use of clean-up or '**end-of-pipe (EOP) technologies**' that control releases of pollutants created in industrial processes by capturing and cleaning up waste streams before releasing them in smaller quantities or in more dilute form into the environment. EOP technologies are the mainstay of the traditional ETS industry as described in Table 1.1. For instance, in the sub-sector of air pollution control, a well-known example is flue-gas desulphurisation (FGD) that reduces the risks from acid rain by removing sulphur from the chimney gases of metal smelting plants, etc.

However, over the last decade, an alternative approach has developed that builds environmental considerations into the design and operation of products and industrial processes using what has been dubbed '**cleaner technology[2]**' (CT) (4). Underpinning much of this move towards what has been called a 'green industrial revolution' (5), CT approaches include:

- 'Green' chemistry - where novel chemical processes and products are developed that inherently present fewer risks to the environment
- Integrated product design – where products are conceived and designed to be inherently less environmentally damaging throughout their life-cycles – i.e. from production of raw materials, through processing and manufacture, to transport, use and after-use.

[1] These include the chemical, metals, pharmaceutical, biotechnology and food and drink industries. Clearly, these themes apply elsewhere in industry (e.g. in energy, engineering, construction and transport), but, for the sake of clarity and brevity, this report focuses on the process industries, as they are significant users of resources and sources of wastes.
[2] Definitions abound, but none is definitive. Cleaner technologies are also sometimes referred to as 'clean', 'sustainable', or 'resource efficient' technologies, and sometimes as 'integrated processes'.

However, CTs are regularly omitted from definitions of the 'core' ETS industry, because of difficulties in distinguishing pollution reduction improvements from general improvements in efficiency (6). Thus, in a company adopting cleaner technology, the share of total costs related to environmental improvements may not be clearly separable from the cost of general efficiency improvements. An example is 'closed-loop' chemical processes, where more efficient processes use smaller quantities of less hazardous raw materials, and where waste products are recovered and recycled within the process stream.

Each of the two approaches has its pros and cons, and can overlap. For instance, when controlling emissions of air pollutants (such as volatile organic compounds), companies that traditionally would have sold EOP technologies, are increasingly examining ways to reduce the creation of the air pollution before capturing the remaining emissions.

A company's decision on which technology to adopt may be driven by a number of factors:

- meeting basic legal and regulatory requirements
- reducing raw material and waste disposal costs to achieve overall cost-savings
- realising strategic business advantage from innovation and sustainable development
- preconceptions, perceptions of risk and attitudes to change
- investment timescales for capital expenditure (e.g. new or replacement equipment).

As well as protecting the environment**, the adoption of environmental technologies presents an important business opportunity**. The OECD has estimated that the 'core' ETS industry is likely to be worth around $300 billion by 2000, and likely to grow to $600 billion worldwide by 2010 (6). However, it has also suggested that the market for CTs might be worth considerably more than that of the 'core' ETS industry (6-8). Here, it reported that, taking only some cleaner technologies into account[3], the wider 'eco-industries[4]' are likely to be worth around $600 billion by 2000, with considerably greater growth potential than the core ETS industry (**Figure 1.1**). This indicates that:

- Cleaner technologies provide increasing value relative to the traditional EOP market
- The cleaner technology market is likely to grow faster than the EOP market.

Both in the shorter and longer terms, then, environmental technology presents a key opportunity for the UK[5] - to serve the UK's own industry and other developed countries, and also to assist developing countries avoid the mistakes made by industrialised nations[6] (9). Nevertheless, while many cost-effective techniques[7] already exist to tackle industrial releases to the environment, their uptake has been slow, as this report shows (1, 10).

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3 for replacement of existing plant only, and not including wholly new clean processes, products or energy

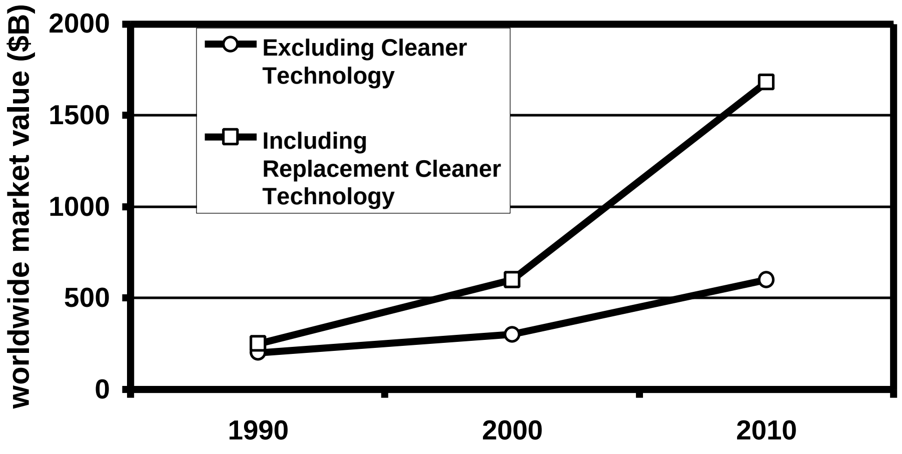
4 A term used by the European Commission in 1994 and adopted by the OECD. The term includes the core environmental technology and services industry plus cleaner technologies "*where pollution and raw material use is being minimised*."

5 Data from the European Commission (8) suggests that, in 1998, the UK had a 12% share of the EU 'eco-industry' market (the second largest share after Germany which had 35%). The EU as a whole had around 33% of the world market share. Thus, the UK's share of the world market is approximately 4%. In clean technology in particular, the EU is felt to be ahead of its international competitors (notably the USA) (9).

6 This latter point is especially pertinent in the context of the Clean Development Mechanism under the Kyoto Protocol to reduce emissions of greenhouse gases to reduce the risks from climate change.

7 The term 'techniques' includes both technologies and management systems.

FIGURE 1.1 VALUE OF THE ENVIRONMENTAL TECHNOLOGY & SERVICES INDUSTRY



Source: (6)

Studies have revealed a broad spectrum of barriers to take-up, including:

- lack of incentive (e.g. weak regulation or enforcement, and perceptions of poor returns on investments[8])
- lack of awareness of the business benefits of environmental management
- institutional and organisational resistance to change (e.g. sunk-costs, narrowly based cost-accounting, inability to innovate, etc.).

Nevertheless, many, including the government, view continual technological and institutional innovation as the key to increasing the long-term competitiveness and sustainability of industry, and enabling the UK to realise its commercial potential. This 'environmental modernisation' (11) would create the situation where wealth and environmental quality would increase at the same time (5, 11-14). To start the process, then, the government has brought together a range of instruments under the umbrella of 'market transformation' to encourage production and consumption of goods and services that meet the objectives of 'sustainable development'[9].

Such considerations are also currently topical because the UK is poised to introduce a new regime for managing industrial pollution – Integrated Pollution Prevention and Control[10] (IPPC). The government is expected shortly to lay before Parliament draft guidance to the regulators on how IPPC should be implemented. The Act requires that the 'best available techniques' (BAT) are used to prevent (and where this is not practicable, reduce) emissions and the impact on the environment as a whole. The latest draft of the guidance (15) points firmly towards the use of technologies that avoid the production of pollution in the first instance (i.e. cleaner technologies), rather than relying on technologies to reduce emissions of pollutants from installations (i.e. end-of pipe

[8] However, many investments made under the government's Environmental Technology Best Practice Programme have been shown to be highly cost effective with short payback times.

[9] see Section 4.3.3 of this report.

[10] EC Directive 96/61/EC – enacted in the UK via the Pollution Prevention and Control Act 1999, and to be implemented through regulations.

techniques). Indeed it is policy of the Environment Agency that it "*will promote the adoption of measures and methodologies specifically targeted at waste minimisation*." (16).

In assisting the Parliamentary debate, therefore, on the future direction of industrial environmental management in general, and on environmental technology more specifically, the Board of the Parliamentary Office of Science and Technology (POST) has decided that an analysis of the drivers, opportunities and barriers towards technological innovation in this area is necessary.

This report, therefore, covers the following topics:

- Chapter 1 provides a brief introduction to the topic and why it is of interest to Parliamentarians.
- Chapter 2 provides a brief historical overview of how industry has responded to environmental concerns, and examines the current drivers and opportunities offered by the two approaches – 'end-of-pipe' and 'cleaner technology'.
- Chapter 3 considers the process of innovation (how concepts and ideas can be successfully exploited) in the context of environmental policy. It examines the meaning and process of 'innovation', the mechanisms for encouraging innovation in the environmental arena, and barriers to realising the potential.
- Chapter 4 discusses issues arising, such as the balance between the various techniques of industrial environmental management; the means to encourage innovation in environmental technologies; and research needs.

2 ENVIRONMENTAL MANAGEMENT IN INDUSTRY

Few would dispute that the environment has become a key business pressure since the 1980s. Many of the major companies in the UK[11] and around the world have recognised this, and have begun to adopt environmental policies and procedures. While there is still a long way to go before it is common across the whole of business, and in particular in small and medium-sized enterprises (SMEs), the picture is now very different from that 20-25 years ago. Increased awareness of environmental issues has created a policy climate in which there is now an 'environmental imperative' (1,4,11,12). This chapter outlines industry's responses to environmental concerns, the regulatory regime, and the scope of technological approaches to tackling industrial pollution.

2.1 Business Drivers for Environmental Performance

2.1.1 Compliance

20 years ago, the environmental debate was characterised by a somewhat simplistic and rather polarised argument. On one side of the debate were those (often in the environmental pressure groups) 'blowing the whistle' on alleged environmental problems (such as acid rain, global warming, ozone depletion, etc.) and who pressed for tight environmental standards. On the other side stood those (often in industry, and sometimes in government) either denying that a problem existed (or that the UK was a contributor to the problem), or campaigning vigorously to avoid or dilute environmental standards. A few voices recognised some problems and argued for cost-effective solutions to them.

Environmental concerns have undoubtedly grown, and legislation has followed. While many in industry fought to avoid the legislation in the first place, others tried to ensure that the legislation was not too onerous (1). However, this approach often proved to be costly in the longer term as the 'ratchet' of legislation tightened. Similarly, there were adverse effects for those presenting themselves in an obstructive light. Thus, those industries which offered unreasonable opposition to proposed tightening of standards, damaged their image; lost influence over the content and form of legislation; faced difficulties with their local communities and the wider public; and sometimes felt the force of direct customer reaction to their environmental performance (through 'green consumerism') (1, 16).

2.1.2 Compliance-plus

Basic compliance with legislation remains a key driver today, but many companies have also recognised that if they can **anticipate** new regulations, they can adopt practices that will put them 'ahead of the game'. Companies adopting this 'compliance-plus' approach may choose to stay just one step ahead of the regulations, i.e. complying with today's and the next generation of standards. Alternatively, they may choose to anticipate

[11] Data from a survey of UK trends in environmental management in industry (9) indicate that 90% of leading UK companies now operate an environmental policy, and 89% have adopted procedures to minimise waste.

developments further in advance, and perhaps even engage in the policy process itself by way of lobbying to influence the shape of future policies and regulation. However, the compliance-plus approach requires some investment by companies in finding out about, or influencing potential legislation, and so many (especially SMEs) may be loath to 'take their eye off of the ball' of their day to day business. As such, compliance-plus is to some extent a luxury that can be afforded only by larger companies, while many small and medium-sized companies struggle to keep up even with current legislation (1).

2.1.3 Cost-cutting

Another key driver has been the recognition that taking environmental concerns into account in business not only avoids possible prosecution or endless catching-up with legislation, but may offer direct economic benefits, summarised in the phrase 'pollution prevention pays'. In particular, the concept of '**eco-efficiency**' as put forward by the World Business Council on Sustainable Development (WBCSD) (**Box 2.1**) has been taken forward by regulators, governments and a few larger businesses in the UK and further afield. Eco-efficiency essentially means 'getting more for less' – i.e. it aims to increase the productivity of resources rather than the traditional approach of increasing the productivity of labour (18).

BOX 2.1 ECO-EFFICIENCY

The term 'eco-efficiency' refers to a combination of economic and ecological efficiency, and is a concept now gaining wider recognition in the business community, as more companies begin to appreciate the positive impact it can have on profits. Originally, the concept was developed by business itself (through the Word Business Council on Sustainable Development, WBCSD), but eco-efficiency has now been adopted by governments and intergovernmental organisations such as the European Commission and the OECD.

The WBCSD states that a company wanting to become eco-efficient should strive to:

- Reduce the material intensity of its goods and services (i.e. amount of material used per unit output)
- Reduce the energy intensity of its goods and services (i.e. amount of energy used per unit output)
- Reduce the dispersion of any toxic materials
- Enhance the recyclability of its materials
- Maximize the environmentally-sensistive use of renewable resources
- Extend the durability of its products
- Increase the service intensity of its goods and services.

Eco-efficiency can be implemented on four levels:
Eco-efficient processes - Making resource savings and reducing the risk or impact of processes allows companies to reduce the costs of production and site operations.
Re-valuing (re-valorizing) by-products - Cooperating with neighbouring and partner companies can turn wastes and by-products into valuable alternative resources.
Creating new and better products - Creating products and services, following ecological design rules with new and enhanced functionality, can boost eco-efficiency. Such innovations can offer companies new and more profitable business opportunities and increased market shares - not only cost savings.
Eco-efficient markets - The WBCSD has described eco-efficiency as "*de-linking growth of welfare from use of nature*". This means that the economy can derive greater value from its goods and services with lower environmental and social impact. Companies can identify opportunities in making markets more eco-efficient or more environmentally-sensitive by searching for products and services that allow more efficient use of resources. Selling services that directly deliver the function of a product to the customer can be profitable and businesses can continue to grow, while reducing use of resources and environmental impact.
Sources: (18-21)

In the UK, the Department of Trade and Industry (DTI) has launched the UK Eco-Efficiency Initiative (UKEEI), which is part of a wider programme within the EU (Box 2.2). Also, in conjunction with the Department of the Environment, Transport and the Regions (DETR), DTI sponsors the Environmental Technology Best Practice Programme (ETBPP, while the DETR sponsors the Energy Efficiency Best Practice Programme (EEBPP). Furthermore, the environmental regulators in England and Wales (the Environment Agency) and Scotland (the Scottish Environmental Protection Agency) have been involved in nearly 70 waste minimisation schemes around the country. These have shown that significant cost-savings can be made by industry using current technologies and techniques to reduce raw material input, energy use and waste production (**Box 2.2**).

BOX 2.2 UK INITIATIVES INTO ECO-EFFICIENCY AND WASTE MINIMISATION

In October 1998, the World Business Council for Sustainable Development (WBCSD) and the European Partners for the Environment (EPE – a Europe-wide 'network of networks' dealing with sustainable development issues), in partnership with the European Commission's DGIII, launched a two-year long European Eco-efficiency Initiative (EEEI). This is an awareness-raising and competence-building exercise to promote eco-efficiency and its benefits across Europe. The UK's contribution to this is the UK Eco-Efficiency Initiative (UKEEI) which is being coordinated by the Department of Trade and Industry (DTI). Its aim is to bring greater coherence to the network of intermediaries providing information to business on relevant eco-efficiency activities in the UK. There are currently well over 100 'environmental business clubs' in the UK, operating nationally or regionally and providing advice on a broad range of environmental issues facing businesses. There are also over 30 waste minimisation 'clubs' concentrating on practical aspects.

A now 'classic' example of a waste minimisation scheme is the **Aire and Calder Project.** This was the UK's first local demonstration of waste minimisation and clean technology. It was coordinated by the Centre for the Exploitation of Science and Technology (CEST) and sponsored by the BOC Foundation, Her Majesty's Inspectorate of Pollution, the National Rivers Authority and Yorkshire Water Services. It was launched on 25 March 1992, and ran for three years. Its objectives were to

- Demonstrate the benefits of a systematic approach to emission reduction
- Focus on procedural changes and clean technology
- Collect accurate data on costs and benefits
- Identify gaps in supply, technology and science
- Examine the utility of the Institution of Chemical Engineers' waste minimisation manual in practice
- Act as a showcase for British expertise.

Eleven companies took part, coming from 7 sectors (railways, food and drink, dyes and pigments, printing, fine chemicals, organic chemicals and commercial laundry). By the end of the project, the eleven companies had identified a total of 901 waste minimisation measures, covering inputs of water, raw materials and energy; and outputs of liquid and other wastes. Total savings of £3.35M were achieved, nearly half of which were related to reductions in raw material inputs. In terms of the pay-back periods for the measures implemented, 63% paid back within 1 year and 34% between 1 and 3 years. Only 3% of the measures paid back in more than 3 years.

The project, therefore, showed that cost-effective waste minimisation measures could be taken by reducing inputs of water, energy and raw materials and outputs of waste. The project also demonstrated the usefulness of a local, club-based approach, and the ability of regulators and companies to work together without any conflict of interest. The results of the project have been used extensively by industry, regulators and government to encourage further waste minimisation projects. For example, the UK Governmnet's Environmental Technology Best Practice Programme (ETBPP) is currently realising savings to industry of £87M per year. Following the success of the Aire and Calder project, the government has been keen to promote waste minimisation within its policies for waste management and sustainable development.

Sources: (22-24)

2.1.4 Customer Pressure

It is increasingly common for companies to insist that their suppliers become environmentally responsible in both the products and services supplied (1). This pressure can apply throughout the supply chain – from the production of raw materials, through transport, processing, to manufacturing and distribution of the end product, through to the use and after-use of the product. It is important to recognise here that the final consumer also plays a vital part in creating this 'supply chain pressure'.

Often supply chain pressure is related not just to environmental concerns but to other issues such as health and safety and product quality – in what has been called 'total quality management' (TQM). The concept of TQM began in the 1980s associated mainly with management systems related to the procedures for carrying out normal business practices. This culminated in the British Standard 5750 (which later became International Standard 9001). After a number of technological accidents involving loss of life, the TQM idea expanded into the management of safety and health issues within industry. Companies with such management systems in place were able to adopt environmental concerns readily into their business practices. **Box 2.3** outlines the current standards for environmental management (ISO 14001 and EMAS).

BOX 2.3 ENVIRONMENTAL MANAGEMENT SYSTEMS (EMS)

Environmental management has become recognised as part of general business management. To promote good environmental management and performance, two complementary schemes have developed that provide a company with recognition that it has taken (and continues to take) positive action to protect the environment.

Eco-Management and Audit Scheme (EMAS)
This scheme (introduced in April 1995 under European law) has been established by the European Union to improve the quality of environmental management throughout European industry, to help companies gain competitive advantage from these improvements and to communicate their progress to the general public.

ISO 14001: 1996 Environmental Management Systems
This is an international industry standard for environmental management. It was published in September 1996, and specifies the scope and means for establishing an environmental management system (EMS).

In March 1997, the European Commission agreed that ISO 14001 met the management system requirements of EMAS, and so registration under ISO 14001 can be used as part of the process of registration under EMAS. Both approaches require independent third parties to verify that the EMS adopted meets the requirements of ISO 140001 or EMAS. The major difference is that EMAS requires that a company reports publicly on its performance, and this statement also must be independently validated.

By September 1998, there were 5,637 sites registered under ISO 14001 (the UK was second only to Japan, and had 650 sites, representing 11% of the total). Under EMAS, by the same date, 2141 sites had been registered, with the UK being 5th with 56 (2.6%) of the EU total.

Source: (25)

2.1.5 Competitive Advantage

Business exists to make profits for its shareholders. However, it must also maintain its wider 'licence to operate' – though compliance with legal and social requirements. As such, society expects business to operate in a responsible fashion: treating its employees fairly; avoiding damage to the environment; acting as a good neighbour to its local community; etc. Consequently, while financial gain remains the key driver to environmental performance in business, there is increasing recognition that wider concerns such as environmental responsibility need also to be considered (26).

The coming together of these three strands into a new business process has been related to the rise of the concept of 'sustainable development'(27). A large number of the major companies operating in the UK (and increasingly world-wide) have stated their intention to move towards sustainable development, albeit an extremely vague concept. Global organisations (such as the WBCSD and the International Chamber of Commerce (ICC)) and UK-based organisations (such as the Confederation of British Industry (CBI) and the government's Advisory Committee on Business and the Environment (ACBE)), have also 'signed-up' to this approach.

The specific strategies adopted inevitably vary from one company to another, and from one business sector to another (1, 28). Nevertheless, the themes of vision, innovation, responsiveness, openness and inclusiveness are common to all. In the context of this report, however, the focus is on the role that innovation plays in the moves towards creating an industrial sector which pays due regard to environmental considerations. Before exploring the issue of innovation in the next chapter the following sections briefly outline the regulatory regime for industrial pollution control, and the range of techniques available for tackling environmental concerns in industry.

2.2 Industrial Pollution Regulation

2.2.1 The Current Situation

In 1976, the Royal Commission on Environmental Pollution (RCEP) published a report (29) in which it drew attention to the fact that pollution is rarely (if ever) confined to one part of the environment. For example, pollutants emitted into the air do not generally stay there, but fall back to earth as dust or in rain[12]. This means that air pollutants can enter other environmental media (such as soil or water), and will often then move between these media. Recognising this, the RCEP warned that controlling the release of pollutants into one medium would most likely have implications for other media, thus requiring a more integrated approach to pollution control, supervised by a single inspectorate.

This concept of integrated pollution control (IPC) passed into law in the Environmental Protection Act 1990 (EPA 1990). This legislation fundamentally reviewed the pre-existing system, and has established a regime that requires reduction in the overall environmental

[12] Air pollutants can also be removed in snow, sleet, fog and mist.

impact of industrial processes across all media – air, water and soil. This concept has been embodied in the idea that the solution adopted for a particular facility should represent the Best Practicable Environmental Option (BPEO). The IPC regime puts more emphasis on the prevention of pollution, rather than its clean-up, and this requires that the BPEO should be implemented using the Best Available Techniques Not Entailing Excessive Costs (BATNEEC).

Authorisations for processes regulated under IPC must be reviewed every four years, taking account of emerging best practice. The intention is that BATNEEC should be dynamic and that this should stimulate innovation in environmental technology design and application.

2.2.2 The New Regime

The Environment Act 1995 created the Environment Agency for England and Wales through the merger of the National Rivers Authority, the Waste Regulatory Authorities and Her Majesty's Inspectorate of Pollution and some parts of the (then) Department of the Environment. The Agency began operations in April 1996, and over the intervening four years has been attempting to 'set out its stall' regarding its approach to meeting its obligations (30). The effectiveness of the Agency is currently the subject of an inquiry by the House of Commons Environment Sub-Committee - this aspect is outside the scope of this present report.

In 1996, the European Union adopted the Directive on Integrated Pollution Prevention and Control (IPPC), which has been implemented in the UK through the Pollution Prevention and Control Act 1999[13]. The new regime builds on the IPC regime developed in the UK, but several key differences are apparent. IPPC covers nearly 4000 more installations than IPC (particularly food production and livestock rearing), and has a much broader list of prescribed substances than on the list under IPC. In addition, IPPC will cover the consumption of raw materials, the efficiency of energy use within a facility, and will control the impact of a facility on the contamination of soil – all of which do not feature in IPC.

IPPC will operate under the principle of Best Available Techniques (BAT). Here, the difference is that the Not Entailing Excessive Costs (NEEC) aspect of IPC has been omitted. Nevertheless, it has been agreed among member states that NEEC is implicit in the definition of BAT, and so cost-benefit and cost-effectiveness considerations will still apply. **Box 2.4** defines what is meant by BAT under the IPPC regime. A key feature of these definitions is that they are flexible, and so much will be left to the regulatory authorities to interpret them on a case-by-case basis. What is clear, however, is that BAT will promote cleaner rather than EOP technologies, but it will not specify any particular technologies to be used. Rather BAT will be decided on a rolling (probably 4-yearly) basis for particular processes by the regulators working closely with industry to identify emerging technologies that have proven commercial viability and environmental effectiveness. This approach is intended to give the operators of IPPC regulated facilities

[13] In England and Wales, powers under the act to make regulations are given to the Secretary of State for the Environment, Transport and the Regions. In Scotland, the powers lie with the Scottish Executive.

the maximum of flexibility in deciding how to comply. Another important feature of the new regime is the timetable for its implementation. The Directive requires that all processes must gain authorisations by 2007. However, this requirement will be met by 'rolling out' authorisations for different sectors at different times. **Table 2.2** shows the currently proposed timetable for the phase-in of industrial sectors coming within the scope of IPPC.

TABLE 2.2 THE IMPLEMENTATION OF IPPC WITHIN LARGER INSTALLATIONS[14]

Phase-in date	Number of installations	Sectors
2000	201	Paper/pulp, primary/secondary steel, textiles, tanneries, cement & lime
2001	186	Ferrous metal processing, non-ferrous metal production & processing, glass, chloralkali,
2002	1629+	Smitheries and foundries, large volume organic (without batch process), food and milk
2003	2143+	Livestock poultry, asbestos, ceramics, polymers, large volume solid inorganic chemicals, slaughterhouses/carcasses, surface treatment of metals, landfills
2004	1456	Livestock pigs, hazardous waste incineration, municipal waste incineration, waste disposal and recovery (other than landfill and incineration)
2005	368	Batch organic chemicals (in multi-purpose plants), large volume gas and liquid inorganic chemicals
2006	603	Speciality inorganic chemicals, organic fine chemicals, coating activities etc using organic solvents, refineries, large combustion plant
2007	4	Coal liquefaction

Source: (15)

Draft regulations under the Act (for England, Wales and Scotland) state (15) that it shall be the duty of the regulator[15] to follow developments in BAT. Similarly, when determining BAT, they will be required to consider *"technological advances and changes in scientific knowledge and understanding"*. These provisions are intended to ensure that the new regime does not act as a barrier to the development of new techniques. However, the wording of the provisions is such that they do not provide a positive stimulus for innovation either. This raises an issue of **the role that the IPPC regime could play in the development of novel environmental technologies**, discussed in Chapter 4.

14 These refer to installations regulated under Part A1 of the Pollution Prevention and Control Act, which represent those posing most risk to the environment. Part A2 processes (those under the scope of Part A1, but of smaller size) are expected to be phased in 1 year after those under Part A1. No timetable has yet been agreed for Part B processes – i.e. small-scale processes (e.g. paint spraying and electroplating works) that had been controlled previously under the Local Authority Air Pollution Control (LAAPC) regime.

15 The Environment Agency in England and Wales, and the Scottish Environmental Protection Agency in Scotland.

BOX 2.4 BEST AVAILABLE TECHNIQUES FOR POLLUTION PREVENTION & CONTROL

Regulation 3 of the Draft Pollution Prevention and Control Regulations states that 'best available techniques' means "*the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.*"

Available techniques means "*those techniques which have been developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the cost and advantages, whether or not the techniques are used or produced inside the United Kingdom, as long as they are reasonably accessible to the operator*."
Best means "*in relation to techniques, the most effective in achieving a high general level of protection of the environment as a whole.*"
Techniques includes "*both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.*"

Schedule 2 to the draft regulations lists 12 factors for which "*special consideration shall be given…bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention*":

1. The use of low waste technology
2. The use of less hazardous substances
3. Furthering the recovery and recycling of substances generated and used in the process and of waste, where appropriate
4. Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale
5. Technological advances and changes in scientific knowledge
6. The nature, effects and volumes of the emissions concerned
7. The commissioning dates for new or existing installations
8. The length of time needed to introduce the best available technique
9. The consumption and nature of raw materials (including water) used in the process and the energy efficiency of the process
10. The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it
11. The need to prevent accidents and to minimise the consequences for the environment
12. The information published by the Commission pursuant to Article 16(2) of the Directive or by international organisations [relevant to the monitoring and reporting of what constitutes BAT].

Source: (15)

2.2.3 A New Direction for Environmental Policy

Traditionally, environmental policy has focused on measures related to the production of goods, and the application of end of pipe technologies to control pollution generated during production. An alternative approach (Integrated Product Policy or IPP) has been developing over the last few years that considers the environmental impact of products throughout their whole life-cycles. This recognises that, by treating a product separately from the processes of its manufacture, there is a danger that environmental impacts will be transferred between process and product, rather than eliminated (31, 32). The key to IPP is life cycle thinking, and an important tool in being able to achieve this is life cycle assessment (LCA). This is essentially an analytical tool that attempts to identify, quantify and assess the environmental impacts of a product from 'cradle to grave' (**Box 2.5**).

BOX 2.5 LIFE CYCLE ASSESSMENT

The international standard ISO 14040:1997 states that life cycle assessment (LCA) is a technique for considering the environmental aspects and potential impacts of a product by "*compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study*." There are essentially four stages to conducting an LCA:

1. Definition of the goal and scope

In defining the goal of an LCA it is essential to identify what is to be achieved (e.g. to develop a new or improved product or service; to compare two or more products; to guide internal policy making; or to apply for an eco-label). Similarly, it is necessary to establish how the results of the LCA will be used, what decisions will be based on the results, and to whom the results will be communicated. The scope of the LCA sets out the parameters and boundaries within which the study will be conducted. It is necessary to identify both the **product system** being considered and the **functional units** involved. The latter are measures of the performance of the functions of the product system (e.g. packaging used to deliver a given volume of toothpaste; or the quantity of detergent needed for a standard household wash).

2. Life cycle inventory analysis

Having defined the goal and function and set the system boundaries of the LCA, the next step is to gather data on the inputs and outputs associated with the various components of the product system. This part of the LCA is generally the most work intensive. The key components of the inventory analysis are:

- **Input** of resources into different operations
- **Flow** of resources and outputs between operations (including recycling, reuse and recovery of materials)
- **Output** of releases from the different operations

A large amount of data on each of these aspects is required. Software and databases are being used more, but uncertainties and gaps in the data persist, exacerbated by the great complexity of many product systems.

3. Life cycle impact assessment

The next stage is to relate the life cycle inventory analysis to the environment. Three elements are most common:

- Selection and definition of the issues to be considered in the impact assessment (e.g. climate change, water pollution, human toxicity, resource conservation, air pollution, etc.)
- Assignment of the inventory analysis results to each impact category (e.g. output of SO_2 affects air pollution and acidfication)
- Category modelling to provide a basis for the aggregation of inventory results within an impact category. Here, the relative significance of each contributor to an issue is evaluated with reference to a common indicator (or potency factor). Examples include global warming potential and aquatic ecotoxicity.

In addition, the assessment stage can seek to assess the overall relevance of an impact 'in the greater scheme of things' – e.g. comparing CO_2 emissions from a plant to the sector, UK, European or world totals. Similarly, it may be desirable to compare the relative significance of different environmental impacts (e.g. global warming with aquatic ecotoxicity). These stages (and particularly the last stage) are often left out, as they are inherently subjective, based on value judgements rather than science.

4. Life cycle interpretation

The final stage is to identify, qualify, check and evaluate information from the conclusions of the inventory analysis and impact assessment of a system. Essentially it is used to communicate the more technical phases of an LCA in a form that is more easily understood and useful to decision-makers.

Ultimately, LCA is an attempt systematically to identify the environmental impacts of a product system from cradle to grave, but it is plagued with uncertainties and data gaps throughout. Making decisions based on an LCA must therefore be accompanied by an appreciation of the reliability and validity of the analysis. Thus, LCA is designed to support better informed decision making and not to replace the decision-making process.

Sources: (33-36)

The scope of an LCA can range from simple 'back of the envelope' calculations to detailed, time-consuming, expensive and highly complex analyses. Also, there is a danger that the 'boundaries' (what is, and is not, included in the analysis) of an LCA can be manipulated to encourage a particular outcome (35). Nevertheless, if used correctly, LCA can be a proactive tool for environmental management that can provide a robust evaluation of the merits of available options and hence provide a stimulus for innovation (37).

LCA can be useful in helping companies to think in terms of the lifecycle of products, but many practitioners caution against its use to define solutions. Rather, it is seen more as a tool to aid and inform decision-making. In the context of the development of IPP, LCA would be useful in aiding the 'environmentally-sensitive design' of products. Here, the aim is to apply environmental and social welfare criteria on the 'front of the pipe'. This is seen in contrast to the idea of eco-efficiency or waste minimisation which could be regarded as being applied 'in the middle of the pipe', and further contrasting with the conventional use of clean-up environmental technology 'at the end of the pipe' (38).

In developing IPP, however, a number of key challenges have been identified (32):

- A need to broaden current environmental regulation and policy away from single sites to a more indirect influence on more widespread (and increasingly global) product systems
- Lack of awareness of the need for environmentally-related policies on products
- Finding a balance between allowing market forces to foster innovative products in the context of continuing economic growth and taking action to ensure that growth is sustainable
- Agreeing a definition of 'sustainable development' and methods to achieve it.

Bearing these challenges in mind, it has been recognised that IPP cannot be developed and implemented in the same way as traditional process-oriented policies. For instance, it would be virtually impossible to establish a monitoring and enforcement agency to act as an inspectorate for a life cycle – particularly where the life cycle may involve many different countries. As such IPP would need to be based more soundly on voluntary actions and market instruments, with public authorities taking the role more of facilitators and arbitrators. In this context, five 'building blocks' of IPP have been identified (32):

- Reduce and manage wastes generated by the consumption of products
- Innovate to develop more environmentally-sound products
- Create markets for more environmentally-sound products
- Transmit information throughout the product chain
- Allocate responsibility for managing the environmental burdens of product systems - IPP aims to improve both production and consumption, and so the role of consumers is as important as that of producers.

Within the UK, the House of Commons Select Committee on the Environment, Transport and the Regions conducted an inquiry into reducing the environmental impact of consumer products (37). In the Committee's report, they stated "*We believe that Integrated Product Policy has potential advantages over the 'traditional' approaches to environmental policy. However, it is too early to judge whether those potential advantages will be converted into real* *environmental gains. The success of IPP will depend upon a number of factors, not least common-sense application and political backing throughout the EU.*"

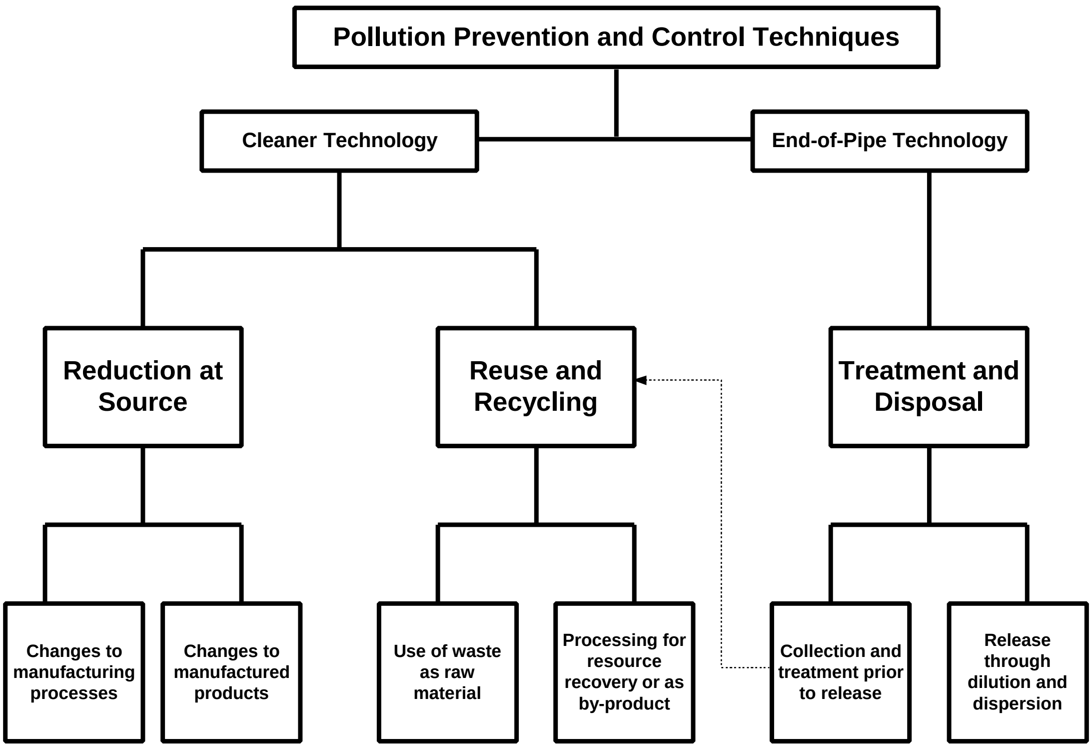
The government's response to the report (39) welcomed the Select Committee's general support for the IPP approach, and stated that *"the impacts associated with consumer products are an increasingly important challenge within the sustainable development agenda, as the scale of consumption and the diffusion of impact sources grow. IPP offers a new policy framework to help address this challenge in a practical and effective way. The Government agrees that the success of the approach will depend on good sense in its implementation and on clear political backing and leadership at EU level"*.

Within the scope of this report, only the first two building blocks have been considered, as the remainder have less of a technological focus, and are perhaps of more relevance to others. The next section discusses the technological means by which industrial pollution can be managed, while the issue of innovation is considered in the next chapter.

2.3 Technologies for Industrial Environmental Management

As discussed in the Introduction, two approaches have developed for the management of environmental impacts from industrial processes: end-of-pipe (EOP) and cleaner technologies (CT). **Figure 2.1** illustrates the differences between the approaches.

FIGURE 2.1 TECHNIQUES FOR POLLUTION PREVENTION AND CONTROL

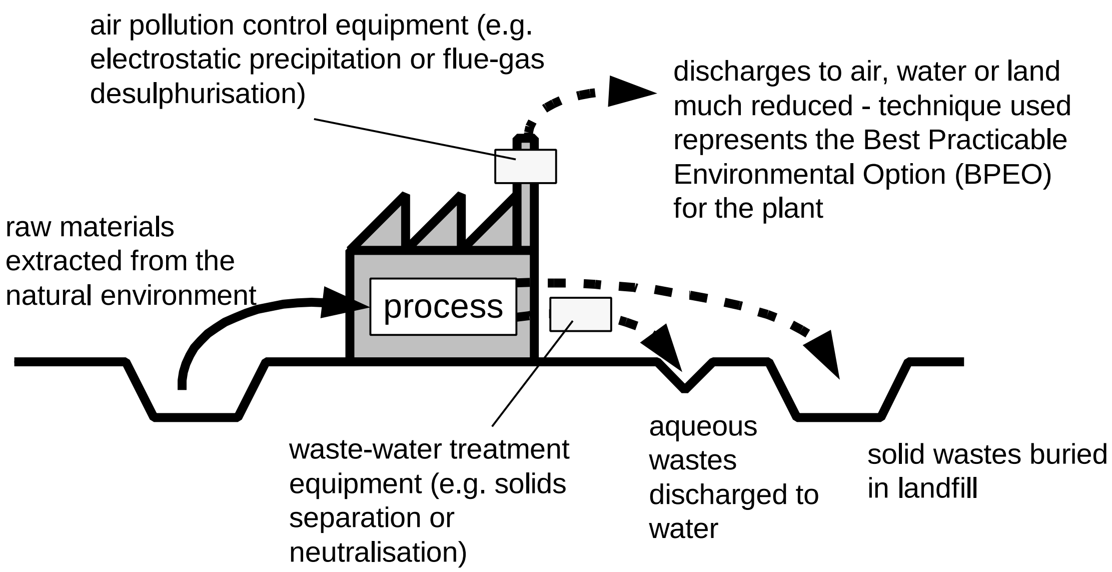


Source: POST - based on (40)

2.3.1 EOP Technologies

The traditional approach to reducing the environmental impact of industrial processes has been to use pollution control equipment fitted to chimneys and effluent pipes. These remove or transform any pollutants produced, whether solid, liquid or gaseous, to reduce their environmental impact. **Figure 2.2** outlines the traditional EOP approach, **Table 2.3** provides details of some technologies employed, with further details in **Box 2.6**. It should be noted that these techniques are able to recover materials for recycling or reuse.

FIGURE 2.2 END-OF-PIPE POLLUTION CONTROL



Source: POST

While traditional EOP techniques are able to reduce the environmental impact of a specific process, in the context of the need to deal with wider environmental impacts they have a number of limitations:

- They tend to capture the pollutants from one waste stream, and transform them into a different form that still requires ultimate reuse or disposal
- The manufacture and use of EOP technologies often involves the consumption of resources and energy, and may itself give rise to pollutants (this may also be the case with CT systems).
- Processes are regulated to ensure that the techniques represent the Best Practicable Environmental Option (BPEO) for the process itself (see Section 2.2.2), but at best only indirectly take account of circumstances beyond the boundaries of the process plant.
- They play no part in reducing environmental impacts further upstream or downstream of the process concerned in the life-cycle of the product being manufactured. For instance, they are not able to reduce the quantity of resources used in the manufacture of the end product, nor can they reduce the environmental effects of the product during or after its use. However, increasingly, the provision of EOP solutions is being combined with improvements in processes themselves.

TABLE 2.3 EXAMPLES OF END-OF-PIPE POLLUTION CONTROL TECHNOLOGIES

Medium	Examples of EOP Technology	Examples of Application
Air	Filtration	Dust removal
	Scrubbing	Flue-gas desulphurisation
	Electrostatic precipitation	Dust removal
	Cyclone separation	Dust control
	Adsorption	Odour control
	Incineration*	Volatile organic compounds control
	Cryogenic condensation	Volatile organic compounds control
Water	Settlement	Solids removal
	Neutralisation	Acidity control
	Incineration*	Toxic substance removal
	Organic digestion	Organic fraction removal
	Adsorption	Toxic substance removal
Land	Compaction and baling	Reduction of landfill volume
	Incineration*	Toxic substance removal
	Composting	Reuse of organic wastes
	Pyrolysis	Waste tyre recycling

* incineration can also be used to generate heat and power, so avoiding the use of primary fuels.

Source: POST and (41)

As an example, metal ore smelters often emit sulphur dioxide (SO_2). This gas can cause pollution problems (such as acid rain) downwind of the emission point. However, the SO_2 can be removed by neutralising it with alkaline calcium carbonate in a flue-gas desulphurisation (FGD) system. This converts the SO_2 into solid calcium sulphate that can then be collected. Thus in this EOP technique, a potential air pollutant is neutralised and removed from the flue gases. Nevertheless, the calcium carbonate used in the FGD plant must itself be extracted from quarries, and materials and energy must be used to build and run the FGD plant.

Also, the solid calcium sulphate produced in the FGD plant still needs to be managed. Two approaches are available, determined by the specific economic circumstances of the plant: either selling the material as gypsum (which is often used in construction materials) or disposing of it in a landfill. Moreover, the chemical reaction that neutralises the acidic SO_2 also releases carbon dioxide (CO_2), the main 'greenhouse effect' gas.

This example shows that tackling one environmental problem alone may create others, unless a more complete life-cycle approach is taken. In this case, different ores, containing less sulphur might be used. Alternatively, higher recycling rates may reduce the need to smelt primary ores in the first place.

BOX 2.6 POLLUTION CONTROL TECHNIQUES

Air Pollution Control.

The reduction of air pollution is a key issue in the process industries to limit adverse effects both on the health and safety of workers and the quality of the environment. Key techniques for air pollution control include:

- **Scrubbing** – passing the air stream through a shower or spray to remove contaminants. Scrubbers using once-through water are increasingly being replaced by recirculating systems that reduce water consumption and liquid effluent production.
- **Thermal oxidation** – the incineration of gas streams to oxidise pollutants to more inert forms. These systems tend to use large amounts of fuel gases, although waste streams containing high concentrations of pollutants can produce self-sustaining combustion.
- **Condensation** – the use of cooling to convert a gaseous pollutant into a liquid, enabling it to be recovered for reuse or for treatment as a liquid. Systems range from simple water-cooled catch-pots on vacuum system vents, though to elaborate low temperature (cryogenic) systems using the vaporisation of liquid nitrogen to produce very high levels of cooling.
- **Filtration** – the air stream is passed through a device that physically (rather than chemically) removes solid particulate materials. These might arise from combustion processes or the use of powders and spray drying. Filtration systems can be simple bag filters (akin to a vacuum cleaner bag), cyclones (akin to the Dyson vacuum cleaner), or electrostatic precipitators that create an electric field on the particulates that are then attracted to oppositely charged plates

Water Pollution Control

Chemical processes often give rise to large volumes of contaminated liquid effluent. The degree of treatment this requires before discharge into the environment depends on the nature of the contamination and the destination of the effluent. Effluent treatment plants vary tremendously in their operation and complexity, depending on the nature of the treatment required. Common techniques employed include:

- **Neutralisation** – the measured dosing of an acid or alkali to adjust pH.
- **Biological Treatment** – the use of microorganisms to digest organic pollutants to reduce the concentration of biodegradable pollutants in effluent. These systems give rise to a sludge waste stream which needs to be disposed of – often to landfill.
- **Adsorption** – physical binding of pollutants onto materials (e.g. granulated carbon and resins) to remove them from waste streams.
- **Settlement** – the removal of solids from liquid effluents by passing the effluent into large ponds of still water where solids can settle out.

Solid Waste Management

Most chemical processes do not generate large quantities of solid waste, although inorganic chemical processes (e.g. titanium dioxide manufacture for paints) can generate solid wastes. Also, wastes arise from ancillary materials, such as filters, resins, packaging and redundant equipment. Similarly, many of the techniques for air and water pollution control generate solid wastes – e.g. solids removed from liquid effluent and dust removed from gases. The most common approaches to dealing with solid wastes include:

- **Landfilling** – the placement of wastes into pre-prepared excavations. Wastes are often compacted and baled before transport to the landfill site, and the landfill itself is engineered to minimise releases of pollutants to the environment.
- **Incineration** – the destruction of pollutants at high temperature. Hazardous wastes are incinerated at specialist facilities.
- **Recycling** – the reprocessing of a waste material as an input in the manufacture of a product.

Case Study – Environet 2000

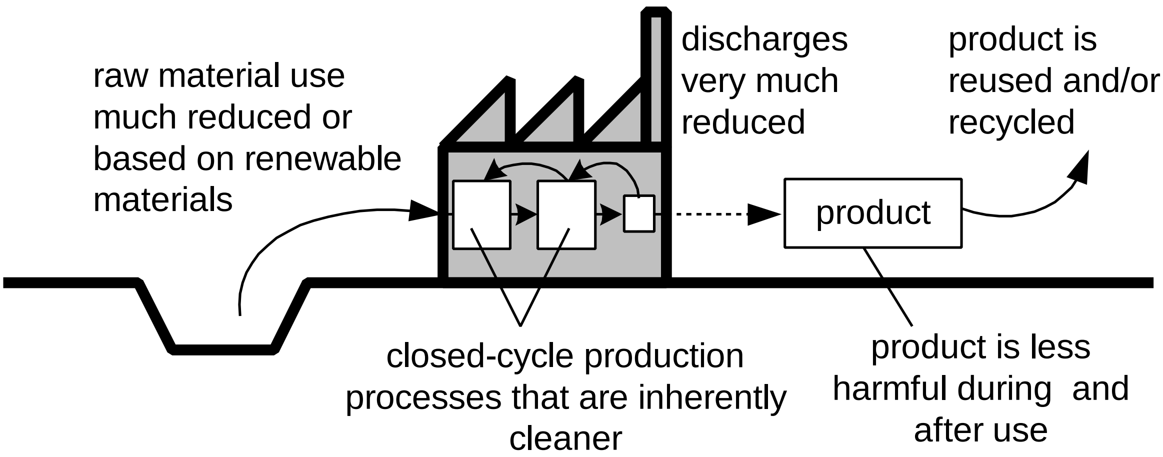
The Chemical Industries Association (CIA) has established a project in the north west of England to demonstrate that adopting an environmental strategy can be cost-effective. The project (Environet 2000) involves 80 companies from 10 industrial sectors. Companies are examining the adoption of waste minimisation, environmental management systems and air pollution control and effluent treatment technologies.

Source: (41)

2.3.2 Cleaner Technologies

Figures 2.1 and 2.2 showed that traditionally, pollution has been controlled by using equipment at the end of one-way industrial processes that simply convert raw materials into products and create waste at the same time. The CT concept involves a step-change in this approach to pollution control. The idea is to prevent the production of pollution in the first place - not merely to control it once it has been created (4). **Figure 2.3** shows how this might work. This also encompasses the idea of Integrated Product Policy (IPP) that was discussed earlier (Section 2.2.3), which aims at encouraging industry to think about products in terms of their possible environmental impacts throughout the whole lifecycle.

FIGURE 2.3 THE CLEANER TECHNOLOGY CONCEPT



Source: POST

The CT concept is underpinned by 6 key interrelated themes (**Box 2.7**):

- Providing **services** based around manufactured products[16] rather than products
- Ensuring that the whole **life cycle** of a product is taken into account
- Maximising the **efficient use of resources**
- Ensuring that the **least hazardous materials** are used
- Improving the manufacturing process to **minimise losses**
- Improving the performance of the product **during and after use**

While the CT concept sounds ideal, it has a number of limitations:

- It may not be appropriate for the provision of services as opposed to products, or where products are custom-designed for a single user, so there is no market for its service elsewhere, or where the product is consumed e.g. food.
- Whole life cycle thinking can be practically difficult. There are often problems in identifying the boundaries of a product system; in using adequate data to identify, evaluate and assess environmental impacts; and in establishing whether, how and where trade-offs need to be made throughout the life cycle (see Section 2.2.3 and Box 2.5).

[16] It would be necessary to ensure that the products that provided the desired service were readily recovered, reused or recycled to avoid the rapid turnover of equipment that would lead to waste disposal problems.

BOX 2.7 THE SCOPE OF CLEANER TECHNOLOGIES

Cleaner technologies improve process manufacturing and products to reduce the use of materials, water and energy and to prevent the generation of waste. This approach is incorporated into a product from the outset, to take account of potential problems throughout its life-cycle – from design, through raw materials extraction, processing, manufacturing, distribution, and use, to after-use. Basic underpinning themes of the cleaner technology approach include:

New Products and Services Concepts
Traditionally, industry manufactured physical products for one-time sale. Increasingly, however, it is building long-term relationships with its customers to service their needs based around a manufactured product (42). Essentially, customers rarely need a product *per se*, but they do need the service it provides. Examples include the supply of document copying (through photocopiers), energy services (through heating, cooling and electrical power devices), motive power (through engines) and even foot comfort services (through carpets). Furthermore, chemicals manufactured by one company are sometimes leased to another to supply the service that the chemical can provide – e.g. as a solvents or a catalyst.

Life Cycle Thinking
Box 2.5 described the concept of Life Cycle Assessment (LCA). Here, the intention is to be able to identify, evaluate and assess the environmental impacts of a 'product system'. This is defined (in draft ISO 14041) as "*a collection of operations connected by flows of intermediate products which perform one or more defined functions*." Product systems are subdivided into 'unit processes', where "*each unit process encompasses the activities of a single operation or group of operations. Unit processes are linked to one another by flows of intermediate products and/ or waste*." An example is the life-cycle of a plastic bottle: oil is extracted, transported to a facility to be refined; transported to be turned into plastic; transported to be turned into a bottle; transported to be filled; transported to the retail outlet; transported to the point of use; transported to a waste management facility (e.g. landfill or incinerator if it is being disposed of, or a recycling plant to be shredded into plastic and then it re-enters the life cycle). An alternative approach might be to recover energy from the waste through incineration, rather than materials through recycling. Here, a detailed 'energy balance' would be necessary to determine the most efficient route.

Increasing resource-use efficiency
Using smaller quantities of materials to achieve the same goals. For instance, only 1% of the energy used by a car actually moves its occupants – the remainder is converted to heat or noise, or is lost through the production of exhaust gases. In chemistry, this concept has become known as 'atom efficiency' – ensuring that each and every atom used in a chemical process delivers the desired function, thus minimising both raw materials inputs, but also waste outputs (see Section 2.4).

Materials Substitution
Using materials in a process that are inherently less hazardous, or those whose processing requires less resource or energy use. Examples may include production of plastics from plant fibres and the use of water as a solvent rather than more toxic organic chemicals.

Process Improvements
Processing rarely (if ever) is 100% efficient, and often valuable raw materials and feedstocks are lost into waste streams. However, these can be separated and reused, so 'closing the loop' in a process. Wastes can also be minimised by eliminating leaks and spills and upgrading plant and equipment to reflect advances in technology. Ultimately, however, wastes will be created, and so it is here that the 'traditional' EOP techniques overlap with cleaner technologies.

Product use and after-use
Here, taking account of life cycle thinking, products are designed to be more durable so they last for longer. Also, they are designed to be readily disassembled - with the components being easily reconditioned, reused or recycled.

Sources: (4,19,35)

- There are physical limits to the extent to which it is possible to improve resource-use efficiency. All physical products need to use some material resources, and improvements in efficiency at one point in the system can lead to increases in the consumption of resources at another point (e.g. recycling consumes energy).
- It may not be practicably possible to substitute one material for a less hazardous one. A less hazardous alternative may not exist, or it may not be cost-effective to acquire and use.
- Process improvements on their own may have diminishing returns. Process loops can be closed, leaks plugged and equipment upgraded. But as with EOP techniques, there are physical and economic limits to the waste reductions that these measures can achieve.
- Designing products for longer life, easy dismantling, reuse and recycling may prove inherently difficult. The objective may best be met where products are leased to provide their services rather than sold, so a service provider has the responsibility for the supply, maintenance, upgrading, recycling and ultimate disposal of a product.
- Progress towards IPP does not necessarily involve immediate changes to product design. Opportunities exist now to improve environmental performance, and so progress can advance in stages. Thus, from maximising 'win-win' gains through good housekeeping and waste minimisation; through the adoption of cleaner processes; to (ultimately) cleaner products.
- Cleaner technologies have a shorter track record than EOP techniques, and their market is more difficult to identify. Consequently, there is lower awareness of their availability and potential, and greater uncertainty and risk involved in their use. For these reasons, companies may be unwilling to invest in CT (this is discussed further in Section 3.3.4 and in Chapter 4, Issues).

2.4 Towards a New Model for the Process Industry

The scope for EOP techniques for continual improvements in pollution control is limited by economic constraints. These may be physical limits or cost-effectiveness considerations even where greater reductions are technically feasible (e.g. it makes no sense to spend more per unit of energy saved than the cost[17] of the energy so saved). Consequently, a new generation of cleaner industrial manufacturing and process technologies is needed that prevents the creation of pollution at source and maximises the efficient use of resources.

Many organisations have recognised the potential of adopting such an approach to cleaner production. Internationally, organisations 'signing up' to the cleaner technology approach include the World Bank, the OECD, the European Commission, the World Business Council on Sustainable Development, the European Chemical Industries Federation (see Section 3.3.3 later), and the Alliance for Chemical Sciences and Technologies in Europe (AllChemE)[18]. Within the UK, supporting organisations include:

[17] Assuming this cost incorporates all externalities such as environmental impacts.

[18] This organisation is an umbrella group of industry, academics and professional institutions that represent the chemical community in Europe. Its members are: The European Chemical Industry Council; the Chairmen of the European Research Councils Chemistry Committees; The Technical Committee for Chemistry of

- Academic and professional institutions such as the Royal Society of Chemistry (RSC), the Institution of Chemical Engineers (IChemE), and the Royal Academy of Engineering (RAE)
- Public research and regulatory bodies such as the Engineering and Physical Sciences Research Council (EPSRC), the Economic and Social Research Council (ESRC), the Environment Agency (EA) and the Scottish Environmental Protection Agency (SEPA)
- Government departments such as the Department of Trade and Industry (DTI) and the Department of the Environment, Transport and the Regions (DETR)
- Industry groups, such as the Chemical Industries Association, a number of Panels under the Foresight initiative (i.e. the Energy and Natural Environment, Chemicals, Materials and Manufacturing Panels), and the Environmental Industries Commission[19] (EIC).

Indeed the World Bank has stated that:
cleaner production should be an essential part of any comprehensive pollution management system, at the enterprise or national level. Significant reductions in pollution loads can often be obtained at little cost, and efficient use of resources and reduction in wastage in industrial production are clearly preferable to reliance on end-of-pipe treatment. (43).

A key development towards this goal has been the advent of what has become known as 'sustainable chemistry', or 'green chemistry'[20] (44, 45). This approach fundamentally alters how products are manufactured, by changing the basic chemistry of a material or a process so that *inherently* it presents fewer risks to health or the environment. At a 1998 OECD workshop on 'Sustainable Chemistry', the following definition was adopted:
"Within the broad framework of sustainable development, we should strive to maximise resource efficiency through activities such as energy and non-renewable resource conservation, risk minimisation, pollution prevention, minimisation of waste at all stages of a product life-cycle, and the development of products that are durable and can be re-used and recycled. Sustainable Chemistry strives to accomplish these ends through the design, manufacture and use of efficient and effective, more environmentally benign chemical products and processes."

In summary, 'sustainable chemistry' involves the design of chemical products and processes to avoid the production of pollution at source by reducing or eliminating the use or production of hazardous substances in the design, manufacture and application of chemical products. **Box 2.8** provides more information on sustainable chemistry. A simple way of illustrating this is in relation to the concept of the chemical reaction. Many are familiar with the idea of chemical reactions where a substance reacts together with another substance to create further substances. This can be expressed as A + B = C + D. In an industrial context, A and B are 'feedstocks', C the 'product' and D 'waste'. In a traditional EOP approach, C is separated from D, and the latter treated before being

European Co-operation in the Field of Scientific and Technical Research; European Communities Chemistry Council/Federation of European Chemical Societies; and the European Federation of Chemical Engineering.

[19] The EIC was established in 1995 as an organisation sponsored by the UK environmental technology and services industry to promote that industry. In its first publication (April 1995) *The World of Opportunities for the Environmental Industry* it stated that "*cleaner technologies are set to replace end-of-pipe abatement*." (page 131). To date, however, EIC have done little to encourage this, and the majority of its effort is in promoting the traditional ETS industry (i.e. end-of-pipe abatement equipment).

[20] This idea originated in 1994, under the term 'benign by design' chemistry (45).

disposed of in the environment in one form or another. The reaction itself might be carried out with the substances dissolved in a solvent, and in traditional chemistry, A, B, C, D or the solvent itself may be hazardous.

BOX 2.8 PRINCIPLES, METHODS AND APPLICATIONS OF 'SUSTAINABLE CHEMISTRY'

The 12 Principles of 'Sustainable Chemistry'

1. It is better to prevent waste than to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximise the incorporation of all materials used in the process into the final product
3. Wherever practicable, synthetic methods should be designed to use and generate substances that pose little or no toxicity to human health and the environment
4. Chemical products should be designed to preserve efficiency of function while reducing toxicity
5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Energy requirements should be recognised for their environmental and economic impacts and minimised. Synthesis should be conducted at ambient temperature and pressure wherever possible.
7. A raw material or feedstock should be renewable rather than depleting, wherever practicable.
8. Unnecessary derivitisation (blocking group, protection/deprotection, temporary modification of chemical and physical processes) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and should break down into innocuous degradation products.
11. Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formulation of hazardous substances.
12. Substances and the form of a substance used in a chemical process should be chosen so as to minimise the potential for chemical accidents, including releases, explosions and fires.

Evaluating Sustainable Chemistry

When considering the environmental consequences of chemical processes, it is essential to consider a number of aspects related to each stage of, and each material used in, the process.

- **Feedstocks and starting materials** – Where the feedstock has come from. Whether it Is from a renewable or depleting source. Whether it is hazardous or innocuous. What implications there might be on subsequent processes.
- **Reaction types** – Whether additional chemicals are required. Whether reactions generate waste.
- **Designing 'safer' chemicals** – How the structure of the molecule affects its function and the nature of hazards presented.

Examples of Sustainable Chemistry

Adipic acid is used in the manufacture of nylon, and traditionally has been made by converting benzene (a known carcinogen), under high pressure in the presence of a number of catalysts, with the reaction taking place in organic solvents. This process gives rise to high concentrations of nitrous oxide (a 'greenhouse gas'). However, the same material can be made using glucose as a starting material, with the reactions carried out in water, in the presence of *E. coli* bacteria to help the conversion. The final stage is to use a catalyst but under much lower pressures than the traditional route. 'Green chemistry' processes avoid the use of a toxic feedstock, minimise energy use, avoid the use of organic solvents and minimise catalyst use.

In the printing industry, ink is conventionally used in a mixture of water and isopropanol (a volatile organic compound that can contribute to air pollution). However, Beacon Press has developed a waterless printing process, whereby the ink is impregnated into a layer of silicon. This process reduces both water use and the generation of wastes. Together with other environmental management measures taken by the company (e.g. using less hazardous chemicals and vegetable-based dyes), this process has improved product quality and operating costs have fallen by 13%. Other examples include cyanide-free metal plating, the manufacture of furnace castings using water instead of alcohol, and vibration of mixtures rather than stirring to reduce emissions of volatile organic compounds,

Source: (44). (See also UKEEI website: http://www.wbcsd.ch/eedata/beacon.htm*)*

A sustainable chemistry approach, however, may avoid the production of the waste in the first place, by using different (non-hazardous) feedstocks, and using a catalyst[21], so that the reaction produces only the desired product (which is itself non-hazardous). This might be expressed as: E + F = G. Similarly, a sustainable chemistry approach would use solvents that were less harmful.

One example of efforts being made to take this approach forward in the UK is the Green Chemistry Network (GCN) set up by the RSC[22]. The RSC has suggested that what is necessary is nothing less than a 're-invention' of chemistry. To this end, the GCN aims to bring together chemists, chemical engineers and biotechnologists in academia, industry and schools to explore and develop the potential for green chemistry. One key aim of the GCN is to change the way that chemistry is taught in schools, to make people aware of the wastes and potential environmental impacts that accompany production processes. For instance, in schools, teachers are being encouraged to ask their students to record the quantities of raw materials they used in making a substance, but also, to take note of the amounts of wastes generated, and to consider alternatives.

Another example is the Clean Technology Fellowship scheme established and jointly funded by the RAE and the EPSRC. Ten Fellowships aimed at creating teams with an international reputation for research in this area. The scheme also intends to influence public opinion so that it is more aware that engineering can provide solutions to environmental problems (as opposed to an allegedly prevalent view that engineering is the major cause of environmental problems!).

The IChemE has stated that preventing the creation of waste is the best way of dealing with it (46). The Institution recognises that some waste minimisation is occurring now, but it considers that what is required is a *"paradigm shift by companies to adopt a holistic approach to their production processes and product lifecycles."* Inherent in this new departure is the need to address, *"not so much how to deal with a particular waste material, but whether the material in question is really necessary, and the systematic use and re-use of materials"* (46). Indeed, the IChemE believes that "moving towards sustainability is a three-stage process: from end-of-pipe clean-up, through cleaner technology [processes] to 'clean' technology [delivering services rather than products]". These stages, it argues are "not necessarily sequential, nor do they have sharp boundaries" – i.e. it is not a case of choosing between an approach based on EOP or CT; rather, both will be required in some degree, but the emphasis ought to be on the latter.

In attempting to define this new model in more detail, the IChemE and the Foresight Process Industry Group[23] have identified a number of features of what a future processing industry might look like (46, 47):

- **Scaled-down, decentralised production** to produce goods on a local scale to reduce environmental impact and increase responsiveness to customer needs. This could be

[21] A substance that accelerates a chemical reaction, but takes no part in it, and is regenerated at the end.

[22] The GCN is based at the Centre for Clean Technology within the Department of Chemistry at the University of York Further details of the GCN can be obtained from the RSC web site at www.rsc.org/greenchem, or from the University of York at greenchem@york.ac.uk

[23] This was set up by the Manufacturing, Production and Business Process Panel and the Chemicals Panel of Foresight to investigate scenarios for a range of possible futures for the process industries.

achieved by using miniaturised process plant such as through the use of very small scale 'nanotechnology' (e.g. the 'factory on a chip') (48). This would also act to save considerable sums in the cost of building and maintaining a processing plant, improve occupational health and safety, reduce risks of accidents in the local community, and reduce local environmental impacts such as landscape and traffic impacts. Such scaling down would also indicate a greater role for technologies for monitoring, automation and remote control of plant and equipment, and hence innovations will be necessary in sensor technology and in information and communication technology.

- **Industrial Ecology -** where production and consumption are seen as two sides of the same coin, and so the potential environmental impacts are taken into account throughout the full life-cycle of a product.

The Foresight Process Industry Group considered that under the 'new model' of the process industry, there will be "*immense opportunities for equipment makers... to establish the UK as the design shop of the world*". It also identifies that a key element in being able to bring about such a shift is research and development (R&D). It states that "*the research needed for the new process industry is very different from that which now feeds the traditional technologies. R&D needs a revolution that is just as dramatic as that facing industry.*" Further, as discussed in Section 2.2.3, there is strong support among EU member states for the development of Integrated Product Policies (IPP). One key aspect of IPP is the need to stimulate innovation to reduce the environmental impacts of products throughout their life cycles. This message has been echoed by the UK Government's Advisory Committee on Business and the Environment (ACBE), which has stated in its October 1998 progress report that "*innovation will continue to be necessary as society moves towards sustainability... there will be significant market opportunities for innovation to meet those needs.*" Thus, as mentioned earlier, many emphasise the role of consumers in stimulating innovation by setting demands on the supply chain.

Innovation, then, is seen by many as the key to being able to make the step-change from end-of-pipe clean up of industrial waste streams to the development and use of cleaner technologies that tackle environmental impacts throughout a product's life cycle. This is the subject of the next chapter.

3 INNOVATION IN ENVIRONMENTAL TECHNOLOGY

As outlined earlier, there are two technological approaches to dealing with environmental risks from industry

- End-of-pipe (EOP) technology to control discharges of waste products to the environment
- Cleaner technology (CT) to avoid the production of waste products in the first place.

Although not entirely distinct, the circumstances in which each approach is adopted will relate to the specific concerns of each firm – i.e. which of the drivers outlined in Section 2.1 it sees as most important. At one end of a possible 'spectrum' of drivers and responses, those firms responding by simple compliance (or through the compliance-plus approach) are most likely to adopt EOP technologies just to meet existing or future legislative standards on existing plant. At the other end, those responding to broader societal concerns related to environmentally-sensitive development may seek to adopt cleaner, resource efficient technologies as new plant is being planned and installed. In the 'middle', those seeking cost-savings or responding to supply-chain pressure may adopt either approach, depending on circumstances. As well as sticks, such as the threat of impending new regulations or supply chain pressure, studies have shown that technological change will be more likely to occur where there are 'carrots'– for instance where there are opportunities to:

- Replace obsolete plant
- Expand the capacity of existing plant
- Reduce overall production costs (including reducing raw materials costs, maintenance and operational costs, liabilities and waste disposal costs).

The relative importance of each of these drivers is poorly understood at present, with conflicting evidence for the balance between regulatory and economic pressures (1) – see Section 3.2.

The Government's sustainable development strategy sees that improving the performance of industry will require a mix of policy instruments. However, there has been no attempt to conduct a comprehensive survey to indicate which drivers apply where, when and why. This raises a significant issue regarding **the relative effort given to the different instruments of public policy that should be employed** – i.e. the relative balance between legislation, best practice dissemination, voluntary agreements and economic incentives. This chapter therefore outlines what is currently understood about the influence of environmental policy instruments on technological innovation in industry, but firstly, the next section briefly describes the nature of innovation itself.

3.1 What is Innovation?

One key element in being in a position to respond to increasing environmental concerns in society, and hence to changing policy requirements, is the availability of novel technologies. This applies equally to EOP and cleaner technologies. Both are sensitive to the processes of 'innovation'. This section outlines what is meant by innovation, the mechanisms to foster and facilitate innovation and some of the common barriers. More generic information on innovation is presented in **Box 3.1** and in **Annex A**.

Innovation has many meanings. The European Commission's (EC) Green Paper on Innovation defines innovation as "*the successful production, assimilation and exploitation of novelty*." The DTI's definition is "*the successful exploitation of ideas.*" Among the many different definitions, the general concept arises that innovation is about creating change for the good. There is widespread consensus that there is a strong link between advances in knowledge, technical progress and long-term growth in productivity and wealth (49). There are more subtle arguments about the most appropriate policy mechanisms to achieve this, but essentially there is agreement that there should be both public and private sector investment in fostering innovation.

There is broad disagreement, however, over where the balance should lie between them, with some arguing that the public sector's role is to fund the underpinning science, engineering and technology research base, while industry should be responsible for picking up these ideas and taking them forward to successful commercial exploitation. Others argue, however, that governments should be more proactive in funding areas of research and development that are most likely to lead to commercial success, while industry's role is to take advanced research and development projects and make the final adjustments to bring them to market. Further still, there is an argument that suggests that both of these views are too simplistic and that innovation is a complex process that involves input from governments, academia and industry (and increasingly from other interested parties) at many different stages of a more iterative process. Thus, innovation is increasingly being seen as a process of creating collaborative networks rather than as a linear 'pipeline' that simply converts government R&D funds into commercial products (49).

Innovation and technology are becoming increasingly important to the economy. For economic stability and growth to persist, innovation is needed on a significant scale. Economic theory has begun to recognise that the level of technology is not an external force to be 'bolted onto' orthodox economic models, but is a key ingredient. Recent theories of economic growth stress technical change, rather than capital accumulation, as the key driver to growth (50). Knowledge is now starting to be regarded as a vital factor in business processes.

Under the EC's definition of innovation, strength is required in the three areas of production, assimilation and exploitation of new knowledge, for current innovation to succeed and, more importantly, future innovation to be encouraged. An innovative economy will not only produce valuable research but also use research rapidly and effectively to produce tangible results. Innovations within industry will benefit the research community through the same links. The links between the research base and industry are vital, therefore, and are the subject of many models of innovation.

The traditional 'pipeline' model of innovation suggests that money and resources pumped into research institutions at one end yield useful results and industrial applications at the other. There are examples of research and discovery leading to industrial changes (a 'technology push' situation) – such as developments in biotechnology (e.g genetic engineering). However, there are also examples where science has had to 'catch-up' with technology, offering theoretical explanations of existing working technologies[24] that have come about through an approach characterised as 'learning by doing' (a 'market pull' situation). As technology can move faster than society's ability to understand it fully, in a highly innovative climate, ideas will flow rapidly in all directions amongst many contributors. This reinforces the concept of innovation as a network process, and hence the linear, pipeline model, while being easy and convenient to envisage, is inappropriate.

In today's business environment, innovation processes are highly interactive and rely upon complex networks. There is now broad consensus that **basic research is more important for providing innovators with techniques to solve problems than for providing an agenda of ideas ripe for exploitation**. The market pull, therefore, provides a stronger driver than the technology push, particularly for innovation based on engineering and physical sciences (51). Therefore, scientific breakthroughs that directly lead to new products seem to be the exception rather than the rule, and it is very much the role of industry to ensure that new knowledge coming externally from the publicly funded research base, or internally from within companies, is matched with successful development, demonstration and marketing.

BOX 3.1 THEORIES OF INNOVATION

At the beginning of this century, Joseph Schumpeter pointed out two distinct patterns of innovation in the marketplace. In the first, an entrepreneur enters a market via a niche, challenging existing firms with the introduction of a new product or process. The entrepreneur exploits the existing level of knowledge to gain a market share in a process called 'creative destruction.' This pattern will create a competitive market. In Schumpeter's second explanation, large, established firms conduct innovative activities in a 'creative accumulation' process. Technological advances gained by these firms contribute to increased R&D and further innovation. Firms will try to re-appropriate as much of an innovation as possible to prevent others from sharing their competitive advantage. This creative accumulation highlights the necessity of patents and the protection of intellectual property. This form of innovation encompasses 'learning by doing'. Knowledge is accumulated as with any other commodity and reserves of knowledge are drawn upon to make future innovation easier. This type of innovation regime is likely to lead to concentration in the market. So there is a strong innovation incentive in this environment. This picture of innovation represents the 'network system'.

Schumpeter also discussed apparent 'long waves' of innovation. These cycles were each powered by a distinct group of technologies and industries, prompting rapid innovation for a period before fading to be replaced by a new group.[25] The first of these cycles represents the industrial revolution (c.1785-c.1845), powered by the iron, textile and other water and steam-driven industries. Other waves have been powered by petrochemicals, atomic power and micro-electronics. The appearance of fresh innovations collapses the previous wave and creates the **conditions** for fresh innovation. Evidence suggests that a fifth wave is already approaching its apex, powered by new, less tangible technologies such as the Internet.[26] If this is the case, then the waves have shortened, as economies become more aware of the importance of innovation and the necessary ICTs become available. So, it may be too late to take advantage of the fifth wave of innovation. It should be pointed out that many economists doubt the existence of such long-waves, but most recognise at least some presence of a long-term boom-recession-recovery cycle, whether fuelled by innovation or not.

[24] Science, for the purposes of this section, is that which asks, and endeavours to answer, the question of how something works. Technology is an application of science, whether that science is yet known or not.
[25] Nikolai Kondratieff, a strict empiricist and one of the architects of Stalin's Five-Year Plans, is the man who first drew attention to these in 1922.
[26] See R&D scoreboard 1999, software and IT services sector

Innovation may be either radical or incremental. A radical innovation involves a totally new product or process while incremental innovations involve minor adjustments to existing products or processes. Nevertheless, incremental innovations are necessary firstly to enable the radical innovation to occur, and then to maximise the efficiency of the radical innovation (17). Incremental innovations, however, will yield successively smaller benefits if applied to an existing technology, and hence there is a built-in driver for continuous radical innovation.

3.2 Policy Drivers for Innovation in Environmental Technology

The preceding section illustrated how the process of innovation works more as a network of interactions between government, academia and industry than as a pipeline that can be characterised as 'public (or private) funds in, technologies out'. This section discusses how this network model of innovation works more specifically in the environmental technology sector, and a key aspect is the influence of how industry perceives and receives environmental policy. The environmental policy 'tool-box' contains a broad variety of instruments to bring about the desired objective of better environmental quality. These range from technology-based environmental standards, through economic incentives such as pollution taxes, through to direct financial incentives such as R&D subsidies, ending finally with communication and networking tools. The effectiveness of the range of tools on bringing about environmental improvement has been studied for many years by researchers around the world (**Table 3.1)**.

The Table shows that, generally, there is no one solution, and that **stimulating innovation and uptake of technologies to improve environmental performance requires a mixture of instruments**, depending on the specific factors and circumstances of the firms and sectors involved. Where firms exist with many different production processes, economic instruments are generally considered to be the most effective. Studies (e.g. 1,17,40,52,53) indicate that economic incentives are more efficient than numerical-based standards, because they allow industry the flexibility to decide the most cost-effective means of achieving greater environmental benefit. However, there is a danger that economic instruments may provide too weak and too indirect a stimulus for technological change – leading to a criticism (e.g. by the House of Commons Trade and Industry Committee during consultation on the climate change levy) that they may be 'blunt instruments'.

The other side of the argument is that that standards-based regulation is the most effective tool to stimulate innovation. Here it is argued that tight regulation gives industry a steady and challenging target at which to aim, and that it also sets a 'tone' in which industry sees longer-term policy commitment to environmental goals becoming ever tighter. Hence, this creates a continuous incentive to find novel way of meeting the standards. Nevertheless, while regulation can encourage improved environmental performance, it does not by itself encourage a shift to cleaner technologies (4).

TABLE 3.1 EFFECTIVENESS OF THE ENVIRONMENTAL POLICY TOOLBOX

Instrument	Example	Characteristics	Effect	Application
Technology-based environmental standards	Readily achieved numerical limits on emissions of pollutants from industrial facilities	- Effective when enforced - Inefficient across many industries	Helps incremental innovation in, and diffusion of, end-of-pipe technologies	Marginal costs of pollution abatement small Economically feasible solutions available
Technology-forcing standards	More challenging, longer-term numerical limits that force new technology (e.g. catalytic converters on vehicle exhausts or 'lean-burn' engines)	- Effective in focussing attention - Forces industry to invest in overly expensive sub-optimal technologies - Low credibility	Stimulates technological innovation	When low cost opportunities available
Taxes	Carbon tax	-Efficient - Industry response uncertain - Danger of weak and indirect stimulus - High costs to industry - Limited political support	Helps incremental innovation in, and diffusion of, end-of-pipe technologies	Where many options available and polluters are willing to respond to price signals
Tradeable pollution permits	US sulphur emission trading	- Effective Cost-effective (environmental benefits achieved at lowest cost)	- Helps diffusion of existing technology - Stimulates innovation	As with taxes, and also where monitoring and transaction costs are not too high
Covenants and voluntary agreements	Reduction of greenhouse gas emissions by the chemical industry	- Compliance uncertain - Possible need for sanctions - Low costs of administration	Helps diffusion of existing technology	Where there are many polluters and techno-logical options. Also where monitoring performance would otherwise be expensive
R&D subsidies	Tax credits for R&D investment	- Danger of funding poor projects - Danger of windfall gains	Stimulates technological innovation	No markets for environmental technology and future policy uncertain. Also where problems over appropriation of benefits
Investment subsidies	Discount on gas-condensing central heating boiler or cavity wall insulation	- Conflicts with polluter pays principle - Danger of windfall gains	Helps diffusion of existing technology	When industry suffers disadvantage due to less strict overseas regulations
Communication	Environmental Technology Best Practice Programme	Focuses attention on problems and availability of solutions	Helps diffusion of existing technology	Where there is a lack of awareness and information
Networking ('match-making')	Business Links programme	- Solutions can be tailored to specific needs - Understanding of processes and products necessary	- Helps diffusion of existing technology - Stimulates innovation	Where there are information failures

Source: (40)

Indeed, if regulations are introduced rapidly and with a minimum of flexibility of action on the part of industry, firms may have little choice other than to seek an EOP solution 'off the shelf', and this may reinforce the 'lock-in' to EOP solutions. This can also occur where EOP solutions are currently thought to represent the best available techniques (BAT) (see Section 2.2), and so their retention could be effectively mandatory.

In the context of the new regime for integrated pollution prevention and control (IPPC) described in Section 2.2.2, this raises a key issue **over how the BAT approach can be implemented to stimulate the development and uptake of cleaner technologies, in line with the government's and regulators' policies**. This is discussed further in the next Chapter.

Studies (e.g. 1,4,17,52) have found, however, that it is often more the **style** of the regulation, rather than the regulation itself, that is a greater stimulus to industry to take action to reduce environmental impacts. Thus, where regulators are more flexible and more constructive in their dealings with the firms they regulate, equivalent regulations can be implemented more effectively. Conversely, strict and inflexible regulation often leads companies to seek readily available, tried and tested (i.e. often EOP) solutions.

Thus the work carried out to date on the drivers for environmental innovation do not provide a clear-cut answer (1), and so 'the jury is still out' with regard to their relative effectiveness. Overall, however, there does appear to be a consensus emerging that economic incentives and flexible regulation are complementary, rather than alternative, to tight regulation.

Table 3.1 also shows which instruments are better suited to stimulating radical innovation (i.e. a step change towards a cleaner technology approach), and those which are more likely to stimulate incremental innovation and the diffusion of existing (i.e. EOP) technology. Thus, most of the instruments described are more likely to encourage the diffusion of existing technology (or perhaps encourage incremental innovation), rather than stimulating radical step-change innovation towards cleaner technology. Therefore, based on the analysis summarised in Table 3.1, radical innovation in environmental technology is most likely to be stimulated using a portfolio of policy tools, including:

- Technology forcing standards
- Tradeable permits
- R&D subsidies
- Networking and 'matchmaking'

Furthermore, it has been reported (52) that a key to innovation in environmental technology is ensuring that the risks faced by firms are minimised. One key aspect of this is ensuring that the overarching policy climate in which industry has to work is stable and credible over the long-term**. The combination of a flexible regulatory style and a stable policy climate creates the optimum conditions in which firms can feel happy to innovate**. This helps firms reduce their costs of compliance and also helps the regulator and government to reduce opposition to environmental policies.

Underpinning the analysis of the drivers for innovation in environmental technology, is the need for further research to learn more about what is technologically possible. For example, the possibilities offered by 'green chemistry' and the use of nanotechnology to downscale chemical plants – see Section 2.3, and how EOP and CT approaches can be integrated.

3.3 R&D in Environmental Technology

The introduction showed that the scope of the environmental technologies was very broad, and that they can be applied across a very wide range of industries. The focus of this report has been on the process industries, and this section highlights the R&D funding opportunities that are available to this sector. Further details of the schemes and programmes are given in **Annex B**. Other schemes and programmes are available for other areas, such as energy production, but these are not considered here.

R&D into environmental technologies is carried out or sponsored by a wide range of national and international public and private-sector organisations. This includes basic science, applied technology, management issues and policy issues.

3.3.1 United Kingdom

- **Government departments** – e.g. the Environmental Technology Best Practice Programme supported jointly by the Department of the Environment, Transport and the Regions (DETR) and the Department of Trade and Industry (DTI). Similarly, the DTI has recently announced a Sustainable Technologies Initiative (STI), and the Ministry of Agriculture, Fisheries and Food is supporting research aimed at developing economic uses for crops as renewable resources for industrial uses (e.g. fibres and starches). Finally in this group, the Office of Science and Technology (OST) of DTI manages the Foresight programme that aims to identify opportunities to create sustained competitive advantage and to enhance the quality of life. DTI also manages the LINK and Foresight LINK programmes that encourage collaboration between academia and industry.

- **Research Councils** – The main supporter of research in this area is the Engineering and Physical Sciences Research Council (EPSRC). In the late 1980s, EPSRC's predecessor (the Science and Engineering Research Council) supported a large-scale Clean Technology Programme. This came to an end in 1999, but no systematic evaluation of the programme's outcomes has been published. EPSRC is currently developing its ideas for a follow-up to the CTP. It currently supports research into environmental technology under the Waste Minimisation through Reuse, Recycling and Recovery (WMR3) Programme. This programme does not specifically support the development of EOP technologies, nor inherently cleaner processes. Rather, it seeks to capture wastes from 'conventional' processes, and ensure that some value is extracted from them before being discharged into the environment. Research into the economic, policy and management issues surrounding the development and adoption of environmental technologies is sponsored by the Economic and Social Research Council (ESRC), under its Global Environmental Change (GEC) Programme.

3.3.2 International Organisations

- **European Union** – The main vehicle for support of R&D into environmental technologies is the European Union's Fifth Framework Programme (FP5), which runs from 1998 to 2002. It comprises four 'activities', many aspects of which have implications for innovation in environmental technology:
- Four Thematic Programmes (Quality of Life and Management of Living Resources; User-friendly Information Society; Competitive and Sustainable Growth; and Energy, Environment and Sustainable Development)
- Confirmation of the international role of Community research
- Promotion of innovation and encouragement of participation of SMEs
- Improvement of human research potential and the socio-economic research base.

- **OECD –** The OECD has adopted the theme of sustainable development as a key activity, and is intending to produce a major report on the subject to the Ministerial Council Meeting in 2001. In relation to environmental technologies, OECD believes that cleaner manufacturing processes are necessary, as well as organisational and behavioural changes (54). To these ends, it supports work on increasing resource efficiency; environmentally-sensitive consumption; economic and environmental polices to encourage the development and uptake of cleaner technologies; the market for the environmental goods and services industry; and innovation and technology. It operates a specific programme on Technology and Sustainable Development, which aims to develop policy recommendations to stimulate the development and use of the most environmentally effective technologies. The primary aims are to:
- Advance understanding of the concepts of eco-efficiency and resource productivity, including the development of indicators which can be applied to specific sectors and technologies
- Better understanding of how enterprises incorporate environmental objectives into their management strategies and the signals needed to stimulate investment in and use of clean technologies
- Develop recommendations for designing environmental and technology policies and related framework conditions which promote the development and widespread use of environmental technologies.

3.3.3 Industry

- **World Business Council on Sustainable Development (WBCSD)** – This is a coalition of 125 international companies committed to the environment and to the principles of economic growth and 'sustainable development'. The WBCSD was formed in January 1995 through a merger between the Business Council for Sustainable Development (BCSD) in Geneva and the World Industry Council for the Environment (WICE), an initiative of the International Chamber of Commerce. In the context of innovation in environmental technology, among its objectives, the WBCSD aims to *"demonstrate progress in environmental and resource management in business and to share leading-edge practices among our members."* (18). The WBCSD operates programmes in Eco-efficiency (see Box 2.1) and Innovation and Technology.

- **Business in the Environment (BiE)** – This is a UK organisation established in 1989 with a mission to encourage business leaders to assess and improve the environmental performance of their companies. One of BiE's main aims is to facilitate communication between businesses to share advice and best practice. To this end it has established an internet-based Environment Business Support Network, which includes case studies of companies making significant cost savings and improving environmental performance through waste minimisation and the use of cleaner technologies. Similarly, it has (with the support of the DTI, DETR and the Environment Agency) established a network of 118 Environmental Business Clubs around the UK (55).

- **Chemical Industry -** This sector provides a good example of innovation in environmental technology, and is regarded perhaps as the most proactive industrial sector (**Box 3.2**). This is because the industry has a very high environmental 'profile', in terms of public attitudes and environmental impacts. Consequently, regulatory and general societal pressures to tackle environmental issues are great. Historically, the chemical industry's response was 'reactive'; generally involving large investments in EOP technologies to meet environmental standards. More recently, however, the chemical industry throughout the world has adopted the 'Responsible Care Programme' (Box 3.2), which essentially requires members to adhere to a Code of Good Environmental Management Practice, and to shift towards proactive approaches to environmental concerns through pollution prevention rather than control (4,56,57). Responsible Care is a broad-ranging concept, but with regard to the context of this report (innovation in environmental technology), the European chemical industry wishes to see greater prominence given to research and technology development in what the European Chemical Industry Council (CEFIC) refers to as 'sustainable industrial technologies' (58). In this area, CEFIC operates it own programme, SUSTECH (also described in Box 3.2).

3.4 Overview

In discussions on innovation, there are often calls from many sides for increasing R&D funding. However, as discussed in Section 3.1, the 'old' linear model of the process of innovation (whereby public R&D converts directly to sales of new technology) is no longer appropriate. Thus, while it is recognised that the generation of new knowledge is a critical factor in economic growth, it is not possible to correlate the level of public funding of R&D with the likely commercial success of products. Rather, innovation is now recognised to be a more interactive process of networking, whereby knowledge is transferred between the different participants – academics, users, interest groups, governments, etc.

Nevertheless, publicly funded research into environmental technologies can increase the range of potential solutions available to industry, but their uptake may be slow - unless they are especially designed as 'black-boxes' that can be widely adopted without the need for local adjustment or expertise. More often, however, high-tech solutions arising from public R&D may be far removed from the current circumstances and requirements of companies (4), and so doubts arise over their practical value. This is especially true if their use requires radical shifts in process technologies and new skills outside of a firm's core competence.

BOX 3.2 THE CHEMICAL INDUSTRY RESPONSE

Responsible Care is a global chemical industry initiative which calls on companies to demonstrate their commit-ment to improve all aspects of performance which relate to protection of health, safety and the environment. This, the industry believes, is the key to maintaining and retaining public acceptance of the industry. The initiative requires:

- The responsible management of chemicals and chemical processes and products over their life cycle
- Commitment to improved performance
- A corporate culture where the environmental management strategy of a business goes beyond minimium regulatory compliance.

Responsible Care is implemented in each country through national chemical industry associations (the Chemical Industries Association in the UK); and in Europe these are co-ordinated under the umbrella of the European Chemical Industry Council (CEFIC).

The programme has 8 features:

- A formal commitment on behalf of each company to a set of Guiding Principles signed, in the majority of cases, by the Chief Executive Officer
- A series of codes, guidance notes, and checklists to assist companies to implement the commitment
- The progressive development of indicators against which improvements in performance can be measured
- An ongoing process of communications on Health, Safety and Environment matters with interested parties inside and outside the industry
- Provision of forums in which companies can share views and exchange experiences on implementation of the commitment
- Adoption of a title and a logo which clearly identify national programmes as being consistent with and part of the concept of Responsible Care
- Consideration of how best to encourage all member companies to commit to, and participate in, Responsible Care
- Systematic procedures to verify the implementation of the measurable (or practical) elements of Responsible Care by the member companies.

SUSTECH is the name given to a collaborative research and development programme in 'sustainable technologies for the process industries'. It was set up in 1994 in specific response to public concerns about the sustainability of the chemical industry's products and processes. The SUSTECH programme is effectively a 'network of networks', each focusing on specific areas of science and technology of interest to the chemical industry. The aim is to promote collaboration to help solve common problems faced by all in the industry. The programme currently operates within the following different areas of technology ('technology clusters'):

- BIOPE - Bioprocess Engineering
- BioSust - Biotechnology
- CAPRI - Competitive Advantage through Process IT
- CRYSOPT - Network for Crystallisation Process and Optimisation
- EXPERINET - A Network for Experimental Methods in Process Development
- FORENTEC - Formulation Engineering and Technology
- HyNet - Hydrogen Network
- MIXNET – Thematic Network on Mixing in the Chemical Industry
- NICE - Catalyst Design and Application
- NICOLE - Contaminated Land Issues
- PRISM - Safety Management
- PI - Process Intensification
- SepTech - Separation Technology
- SPIN - Particulate Solids Processing
- ERNST - European Research Network for Sustainable Technologies is a Targeted Research Action under the European Union 4^{th} Framework Programme [FP4] and has links to SUSTECH). It operates its own 5 technology clusters: modelling, simulation and control of production processes; instrumentation and sensors; catalysis; membranes and waste water treatment; and bio-process technology.

Sources: (56-59)

As well as increasing the range of potential solutions, publicly funded R&D often points to areas where further incremental innovations are necessary to enable radical innovations to proceed, as discussed earlier in Section 3.1. For example, when installing a new cleaner process, there may be a need to improve the efficiency of other parts of a processing facility (e.g. pumps, pipe-work, etc.).

Similarly, technological innovations are rarely implemented without changes in the management or organisation of a firm, and hence innovations may also be required here. For example, new expertise may be needed, and staff may require retraining to use the new equipment or adopt new operational procedures (often within the scope of an environmental management system[27]). Also, with cleaner technologies and, in particular, whole lifecycle thinking, decision-making practices (such as investment timetables and accounting practices) may also need to adapt.

Moreover, as discussed in Section 3.1, there is an argument that basic research is more important for providing innovators with techniques to solve problems than for providing an agenda of ideas ripe for exploitation. In this way, publicly funded R&D fulfils a second function – that of education and training of a new generation of scientists and engineers, thereby providing industry with access to expertise and highly-trained staff.

It is generally accepted that publicly funded R&D is not good at 'picking winners'. Because of this, the focus of science policy has shifted towards stimulating collaboration between the actors involved. An important example of this in the UK is the **Foresight Programme** (Section 3.3.1). The first round of Foresight is acknowledged to have 'broken the ice' between many in industry and academia and to have identified priority areas for further consideration. This networking role is now being taken forward into Foresight 2000, with much emphasis on creating collaboration and ensuring that progress is made using cross-cutting themes such as 'sustainability'.

Ultimately, however, successful innovation in environmental technologies takes place, not in a laboratory, but within a company. Indeed, the House of Commons Science and Technology Committee concluded (51) that the science and engineering base was not lacking in good ideas. Rather, the failure to innovate successfully was because of a lack of investment by industry in the development of products, limited demonstration of their worth, and poor marketing. The drivers described above can be viewed, therefore, from a perspective offered by three 'models' of how industry takes on environmental concerns, and the technological choices it makes in response. These models are summarised in **Table 3.2**.

At the firm level, four factors in the strategic management of companies have been identified that determine which 'model' firms follow in their investment decisions relating to environmental innovations: information, confidence, managerial capacity and financial capital (62). **Table 3.3** sets out how EOP and cleaner technologies 'measure up' against these factors.

27 Increasingly, environmental management systems are being developed so that they are integrated with management systems for health and safety and also for general product or service quality. This is the concept of total quality management (TQM).

TABLE 3.2 INDUSTRY TECHNOLOGICAL RESPONSES TO THE ENVIRONMENT

	'Regulated Industry'	'Greening of Industry'	'Industrial Ecology'
Nature of response	Reactive compliance with technology-based standards	Proactive improvement in environmental performance ('compliance-plus')	Increased resource efficiency to provide competitive advantage
Driver for innovation	Regulation	Market opportunities and policy pressures (achieving 'double dividends')	'framework' policies to encourage market competition (meeting the 'triple bottom line')
Focus of innovation	Pollution abatement ('end-of-pipe' clean-up) and waste management	Process change ('cleaner production')	Novel products and services involving cleaner design and lifecycle thinking
Source of innovation	Equipment suppliers	Environment integrated into the firm's technology strategy	New market entrants provide radical new service packages
Applicability to sector	Mature sectors	Sectors selling to final consumers	Knowledge-based industries
Current position	Most firms	Few firms	Few firms

Source: based on (61)

TABLE 3.3 THE ATTRACTIVENESS OF INNOVATION

Factor	EOP Technology	Cleaner Technology
Information	High – considerable information available and widespread on economic and environmental performance.	Low – little information available or widespread on environmental or economic performance.
Confidence	High – technologies well proven and in widespread use.	Low – technologies in many areas not yet developed or well proven. Use is not widespread.
Managerial Capacity	Low – little managerial effort necessary to explore and implement options.	High – considerable effort necessary to explore the potential for radical innovations.
Financial capital	Low – technologies often available cheaply and readily. Payback times often well established. Risk is low.	Can be high – technologies are integrated into processes, and hence not 'off the shelf'. Costs and risks can be high.

Source: based on (17)

The table shows that, because of their relative novelty, companies are less likely to explore innovations in cleaner technologies compared with EOP technologies. However, recognising the longer-term environmental and economic benefits, the policy climate is moving towards encouraging industry to move from the 'Regulated Industry' model towards the 'Greening of Industry' and 'Industrial Ecology' models, through the development and uptake of cleaner production, products and services. The issue remains, therefore, over **the most effective means by which the government can encourage innovation in environmental technology** (4,52), for example by stimulating the development of the technology itself; aiding the diffusion of knowledge and best practice; or seeking to change consumption patterns through market transformation.

4 ISSUES

While considerable efforts are being made to improve the environmental performance of industry, there are some doubts whether small improvements in the performance of traditional 'end-of-pipe' clean-up technologies can continue to meet ever-tighter environmental standards. Indeed, there is a broad consensus that a 'new model' for industry is necessary, based on 'cleaner technologies' which (as far as is possible) minimise the use of raw materials, energy and water, and aim to prevent the production of waste throughout a product's life-cycle.

Such a change is already occurring (albeit modestly), and, over the last five years, there is some evidence that cleaner technologies have increasingly started to replace end-of-pipe (EOP) techniques. (63, 64). However, a wholesale shift to an industrial system based on cleaner technologies would be radical compared with the nature of manufacturing today, leading some to refer to such change as a 'revolution' (5), a 'reinvention' (RSC) or a 'paradigm shift' (IChemE) in industry.

A key issue is the **timing of such a shift**. It is possible for existing EOP technologies to meet current environmental standards, and, on the whole, they have been adopted mainly as a reaction to the need for immediate compliance with regulatory standards. Some EOP technologies have been adopted, however, where businesses have recognised economic benefits, in terms of reducing waste treatment and disposal costs, and this can entail improvements to processes at the same time. In the near future, EOP technologies are likely to continue be the chief means by which businesses can meet environmental standards. However, it is worth remembering that, although there are still many opportunities to be gained through incremental changes, these have diminishing returns, and their capability is ultimately limited by both economic and physical constraints. Continued improvement in environmental performance under these circumstances will, therefore, become increasingly expensive and continued improvement possible only through a step-change in technology.

Environmental policy is now developing towards a regime where the impacts of both the production and consumption of products are brought together, through **the integration of product design and processing that takes account of potential impacts throughout a product's life cycle**. Consequently, the simple control of pollutants at the end of each processing phase is unlikely to provide the most efficient means of reducing impacts throughout the life cycle of a product. So, continued use of EOP technologies as the primary means of reducing environmental impact is unlikely to be sufficient under an integrated product policy (IPP) regime. Moreover, the future shape of the process industry is envisaged to be one where processing plants are smaller, closer to their customers, safer and more environmentally benign. Finally, in helping the developing world to industrialise, and the countries of the former Soviet Union and Eastern Europe to modernise their economies, cleaner technologies may provide a more long-term opportunity for wealth creation without creating environmental damage (i.e. to develop a more environmentally-sensitive industry). It is under this medium to long-term scenario that cleaner technologies may 'have the edge'.

This chapter highlights a number of key issues arising from consideration of how industry might best tackle its environmental problems, and examines how innovation in environmental technologies could be encouraged.

4.1 Environmental Management in Industry

After decades of debate, it is now widely recognised that economic growth need not necessarily increase environmental degradation. The key is increasing the 'environmental efficiency' of industry (i.e. the amount of damage per unit output). This can be achieved by structural changes towards a service-based economy; using renewable and less hazardous materials in products and processes; improving 'resource efficiency'; and designing environmentally benign products. This approach can be implemented in industry through the use of technology, but management practices and innovation also play central roles. Changes on the larger scale would also be necessary, such as developments in infrastructure (e.g. land-use, transport, and the use of information and communication technology).

An important question is **whether public policy has any role to play in a shift towards such 'environmental modernisation'**. This may simply occur through the rational response of industry, in the face of a myriad of business pressures and may not respond well to deliberate intervention. However, as discussed in Chapter 3 (Table 3.1), there is increasing evidence that environmental policies do have some effect on the responses of firms to environmental pressures. The question arises over **which policy, or mix of policies, is most effective in delivering the end-point of a competitive industry with a smaller environmental 'footprint'**.

It should also be borne in mind that improved environmental performance by industry might flow, as an ancillary benefit, from actions primarily designed to address other considerations. Companies face many business pressures, of which the environment is just one. Nevertheless, environmental pressure is the only reason for deploying EOP technologies, but cleaner technologies may have many more benefits beyond those specifically related to the environment (such as improved productivity). In this context, the Government's view is that *"improvements in environmental performance are simply by-products of better performance overall"* (65).

Cleaner technologies are rarely an end in themselves, but are the likely outcome of businesses seeking innovations to improve all-round competitiveness, and so may be more accurately described as 'resource efficient' (or even 'sustainable') technologies. This section outlines some of the issues arising from changes in the nature of business itself, and how these technologies fit into this.

4.1.1 A New Model for Industry – From Products to Services

The nature of manufacturing has changed dramatically in the last decade, with the advent of techniques such as 'just-in-time' deliveries, and the rise of formalised quality management systems. These represent examples of the wider concept of 'business process re-engineering', which seeks to improve efficiencies from the design stage, through the manufacture to the delivery, use and end-of-life of a product. Here, the Manufacturing, Production and Business Process Panel of the first round of Foresight (see Annex B), identified, among other things, that manufacturing companies become more effective when they orient their business around the supply of services based on products, rather than providing products themselves. The role of quality assurance and supply chain management are also important here.

Nevertheless, the Foresight Process Industry Group (FPIG) stated that the process industry *"remains relatively untouched by many modern business processes. It has not felt the pressure from customers that has driven a revolution elsewhere in manufacturing"* (47). However, signs of change are apparent. For example, there has been a trend towards small-scale processing moving closer to the customer, e.g. the rise in 1-hour, local photographic development, in-store bakeries, and micro-brewing. On a larger scale, industrial gases are now often made where they are used, and aspects of the process (e.g. the use of chemicals such as catalysts and solvents) are often provided on a service basis. Here, the solvent supplier **leases** the solvents to another company, and reclaims them after use. The liabilities for product development and waste management remain with the solvent supplier, thus reducing costs to the user.

FPIG considered, therefore, that as the process industry moves to the 'new' business model, production will continue to become decentralised, with operations carried out in smaller, more environmentally acceptable and responsive process plant. However, in taking this new model forward, it is necessary to ensure that academics, equipment manufacturers and industry are aware of each other's capabilities and constraints. In terms of public policy, then, this raises a question over **the role of government and public bodies in encouraging and assisting the necessary knowledge transfer** (see later, Section 4.2).

4.1.2 Resource Efficiency – The Factor 'X' Debate

Society exerts two pressures on industry – to produce goods that have low environmental impact, and to produce goods at competitive prices. Traditionally, these two objectives have been seen to be mutually exclusive, but there is growing evidence that this is not so. Indeed, the concept of environmental modernisation sees them as mutually supportive. One of the keys to achieving this is the idea of '**resource efficiency**' – which has been described as 'doing more with less'. Here, the objective is to increase the value gleaned from natural resources while, at the same time, reducing the environmental burden caused by extracting, processing and disposing of the resources consumed.

Popularly, this concept has been referred to as 'Factor Four', or 'Factor Ten', or even 'Factor Twenty'. For example, the Factor Four idea is to double wealth while halving resource use. The precise factor by which resource productivity can and should be increased (and the time-scale in which this can be achieved) is not known, and something of an academic debate has started over the value to ascribe to Factor 'X'. As we do not (and perhaps never will) know enough about the environmental impacts of the use of natural resources across the economy and throughout the world, the precise figure cannot be determined reliably. However, the concept offers a point of departure for a wider debate about how resource productivity can be improved, and at what rate.

As discussed in Chapter 2, the traditional approach to controlling environmental impacts from industrial processes has been to install EOP technologies. However, this discussion also highlighted a number of limitations of such an approach, key among them being that:

- EOP techniques have limited capacity to reduce raw material inputs to a process, although they are sometimes associated with minor improvements in process efficiencies, and can be used to separate and recover raw materials for reuse or recycling
- EOP equipment itself requires natural resources in its manufacture and operation
- Unless designed with an approach that considers the impacts across the lifecycle of a product, the use of an EOP technique to solve one environmental problem may create or exacerbate another.

To increase resource productivity radical changes in the approach to manufacturing, that look beyond merely controlling the waste streams from conventional processes, are necessary. This points towards the development and deployment of cleaner technologies that consider life cycle impacts – from raw materials to products.

4.1.3 Pollution - Prevention or Control?

EOP technologies are in widespread use. According to a survey conducted for DETR on environmental expenditure in UK industry in 1997 (64), £827M was spent on EOP equipment, whereas cleaner technologies (referred to in the survey as 'integrated processes') accounted for £334M. The figure quoted for integrated processes is likely to be an underestimate, as the survey collected only data on expenditure that was specifically aimed at environmental protection. However, as discussed earlier, investment in such technologies may be undertaken for many reasons (e.g. to achieve greater production efficiency, to cut costs, or to replace redundant equipment), but the survey would not have picked up these expenditures. The 'true' expenditure on integrated processes, then, is not known at present, so that one option is **to design and conduct a survey aimed specifically at collecting information on the levels of, and motivations for, investment in cleaner (or integrated) technologies.**.

Despite the absence of comprehensive data, academic studies have been conducted on the uptake of cleaner technologies, based on empirical research into a small number of examples in a limited range of industrial sectors. These indicate that they are 'very thin on the ground' and most often limited to a small number of large companies operating in sectors that are particularly exposed to environmental pressures. For instance, the chemicals sector has developed the Responsible Care Programme (see Annex B) to help drive improvement in its environment, safety and health performance. At the same time, however, there is a growing body of evidence that demonstrates that waste minimisation and cleaner technologies have tangible economic and environmental benefits, often with short (i.e. less than 3-year) payback periods (23).

Table 4.1 contrasts a number of features of EOP and cleaner technologies. It shows that EOP technologies have lower short-term costs, but offer limited potential to improve environmental performance (with increasing costs as the limits are approached). By contrast, cleaner technologies are more expensive in the short term, but offer greater potential for continued improvement in environmental performance, with the costs becoming lower relative to EOP in the medium term.

TABLE 4.1 CONTRAST BETWEEN EOP AND CLEANER TECHNOLOGIES

Feature	EOP	Cleaner Technologies
Primary objective	Environmental protection	Resource efficiency
Process adaptation	None required	Often radical adaptation required – including product redesign
Purchase and installation cost	Low	High
Market	Distinct and high profile	Not distinct and difficult to identify
Information on economic and environmental performance of technologies	Widely available and well disseminated	Not easy to identify as difficult to separate from general process efficiency in an integrated process

Source: based on (17)

These factors come together to create the situation where EOP technologies enjoy the benefits of a good track record and economies of scale. Cleaner technologies, however, are less easily identified, and their environmental and economic performance is more difficult to pinpoint; especially as environmental protection is rarely the primary motivation for their installation. Consequently, some argue that this creates an unlevel playing field, with an in-built advantage towards EOP technologies (17).

It should be borne in mind, however, that EOP technologies are still likely to be needed in a future based on cleaner technologies. Firstly, EOP technologies will be needed in the short to medium term while cleaner technologies are further developed and disseminated. Cleaner technologies are unlikely ever to be entirely waste-free, and so a 'new generation' of EOP technologies will still be required for in-process recycling, recovery and reuse of materials, and for cleaning up residual waste streams.

Overall, then, debate over whether EOP or cleaner technologies should be pursued is a rather simplistic one. Each approach has its relevance to existing systems (Table 3.2). There is a general consensus that, in many sectors, EOP clean-up still offers the most cost-effective solution at present (especially for improving the environmental performance of existing facilities). Some (e.g. the Environment Agency) have estimated that this situation may continue over the next decade, but argue that ultimately, EOP technologies cannot deliver continuous improvement in environmental performance throughout a product life-cycle. The scale of their use will depend on the levels of ultimate limits to emissions and discharges, which may be above what is technically feasible. In the longer term, cleaner technologies may come to dominate because they allow further progress in economic efficiency.

Also, as shown in the Introduction, estimates published by OECD (Figure 1.1) indicate that the value-added gained from cleaner technologies is greater than that from EOP solutions. Similarly, the market for cleaner technologies is likely to be much larger, and grow at a faster rate, than the traditional 'core' environmental technology and services market. Consequently, **the cleaner technology approach is likely to represent a far larger and more lucrative market than that covered by the traditional environmental technology and services industry**. Indeed, this has led some (e.g. the Economic and Social Research Council[28]) to suggest that, because the UK has been slow to recognise this, the country is "*missing the green wave*".

In terms of public policy, then, consideration needs to be given to **how the UK can maximise the longer-term potential for the development and supply of resource efficient (cleaner) technologies, while maintaining or increasing its market share in traditional and new-generation EOP technologies**. Here, it is interesting to note that the government (through its Joint Environmental Markets Unit, JEMU[29]) is increasingly promoting environmental technology, not on the basis of enhanced environmental performance, but on the basis that cleaner technology is more resource efficient and can, therefore, save companies money and improve overall performance. This indicates that industries around the world are less likely to respond to the message of environmental rectitude, than to pursue their desire to cut costs and increase profits.

4.2 Encouraging Innovation in Environmental Technology

4.2.1 The Innovation Process

Chapter 3 discussed the process of innovation, and highlighted that the so-called 'linear model' (whereby publicly funded research and development leads inextricably to commercial success) is no longer appropriate[30]. Over the last decade a new model of innovation has emerged that sees the process as being based firmly on interactions between the government, research councils, academia and industry, in 'networks'. Here, the main function is to facilitate the transfer of information, formal knowledge, and tacit understanding between the actors.

Innovation can occur in two forms – either incremental or radical. The model of innovation suggests that both are important and not readily distinguishable. Incremental innovations eventually 'run into the buffers' of their own physical and economic limits, and hence provide an incentive for more radical innovations. Also, once radical innovation happens, incremental innovations are still required to optimise the performance of the new system.

However, despite the widespread acknowledgement of the benefits of innovation, the process is beset with barriers (Annex B). Chief among these are:

[28] ESRC, 2000. "*Producing Greener, Consuming Smarter*". Global Environmental Change Programme, Economic and Social Research Council.
[29] JEMU was set up by the DETR and DTI to help promote the excellence of the UK's environmental industry. Originally it had promoted 'end-of pipe' technologies as a way of solving environmental problems, but in more recent years, the message has shifted to one of resource-efficient technology that has a range of business advantages, only one of which is improved environmental performance.
[30] Indeed, some commentators regard the linear model as "*not only inaccurate, but also harmful*", but that this model is still prevalent in many policy makers' thinking (Tait, J. and Williams, R., 1999. Policy approaches to research and development: foresight, framework and competitiveness. *Science and Public Policy*, April 1999, pp.101-112).

- **Innovation culture** and the perceptions of the risks of innovation relative to the benefits
- **Legal framework** especially the treatment of intellectual property[31] and business failures
- **Macroeconomic conditions** such as inflation, interest rates, and their impact on stability
- **Management of company priorities** and how innovation fits into these (particularly product development, demonstration and marketing)
- **Artificially high and unsustainable levels of R&D** (e.g. the 'Acceleration Trap' and the 'R&D Race' see Annex B)
- **Lack of awareness of government support** and the complexity of the 'maze' of schemes that are often still embedded in the now discredited linear model of innovation
- **Regulation** that hampers information exchange within innovation networks.

4.2.2 Drivers and Barriers

The drivers of, and barriers to, innovation outlined above apply across the economy. In the context of environmental technologies, however, Section 3 outlined a number of key drivers:

- Avoidance of prosecution for failure to comply with legal requirements
- Opportunities for cost-savings related to resource use and waste disposal
- Pressure from customers higher up the supply chain
- Maintenance of company image and competitive advantage.

The extent to which each of these drivers acts to motivate industry is not well known. Table 3.2 suggested that the majority of industry follows the 'Regulated Industry' model, where the prime motivating force is regulation and the key response is to adopt end-of-pipe solutions to comply with technology-based standards. Table 3.2 suggests that far fewer firms have adopted either the 'Greening of Industry' or 'Industrial Ecology' models (61). Nevertheless, there have been no comprehensive surveys to determine which drivers apply where and in which circumstances. Thus, it is difficult to know which policy instruments can and should be used to encourage companies to invest in environmental management. This raises the danger that a range of policy instruments is being deployed without the means to provide a comprehensive evaluation of their impact. One option, therefore, is for **the UK Government and the devolved Executives to commission a comprehensive survey of business responses to environmental concerns**. This should bear in mind the issue discussed above - that investment in cleaner technologies, is unlikely to be driven solely by environmental considerations. Any such survey should therefore examine **how firms include environmental improvement within their overall commercial innovation strategies**. Despite the advantages of a shift to cleaner production, products and services, few companies have moved in this direction. This suggests that there is also a wide range of barriers to investment in environmental management in industry (**Box 4.1**). Despite the numerous barriers, Chapter 3 showed that there are a number of different tools of environmental policy that can be used to overcome them. As outlined earlier, however, there has been no attempt

[31] See POST Report "*Patents, Research and Technology*", March 1996.

to measure their relative effectiveness throughout UK industry, and so it is difficult to say which tools are the most appropriate.

BOX 4.1 BARRIERS TO INVESTMENT IN ENVIRONMENTAL MANAGEMENT

Financial and Economic Barriers

The traditional approach has been to assume that, in a world where people possess all relevant information, they can make rational decisions based on price signals that take account of all true costs. It is assumed, therefore, that resource use is optimised (i.e. there are no inefficiencies). Any deviation from this situation is generally regarded as a failure of the market. Thus, 'market failure' barriers include:

- **Imperfections in information**, preventing economically efficient decisions, especially where the information relates to 'public goods' such as health and environmental quality
- Existence of **split incentives**, where there is a mismatch between the party paying the costs of installing the efficiency measures, and the party receiving their benefits (the so-called 'landlord-tenant' problem)
- **Disproportionate costs** (money, time or effort) to transmit or receive information about the environmental properties of a device or system ('adverse selection')
- **Imposition of strict investment criteria** by a financier ('principal') on an investor ('agent') to compensate for imperfect information, and the risks this carries.

Institutional Barriers

Decisions are not always made on the grounds of pure rational economic self-interest. Indeed, many barriers to environmental efficiencies appear at the organisational and institutional level. Examples include:

- **Cultural ignorance** or **organisational routines**, that may systematically neglect environmental, interdisciplinary and cross-sectoral issues, and result in under-investment
- **Organisational structures** may create incentives for inefficient design (e.g. engineers being paid relative to the cost of equipment installed, rather than energy or resources saved).
- **Lack of sufficient power** by responsible for environmental management may within an organisation.

Behavioural Barriers

Barriers also result from a series of actions that take place at the individual level:

- **Bounded Rationality** – where decisions are made on the basis of limited information, using rules of thumb and routines, and where often the goal is to provide a satisfactory solution, rather than an optimum one (which is the goal of economic theory)
- **Inertia** – where people are resistant to change because they are committed to what they are already doing (this may persist even after the need for change is acknowledged)
- **Form of Information** – where the form of information is found to be as important as cost in determining whether people will take up the measures being proposed (e.g. in advertising, the same information is presented to different audiences in different forms, so that it resonates with their own concerns).
- **Credibility and Trust** – where people respond differently, depending on the source of information (e.g. utilities, national energy agencies, professional bodies, government departments, or personal contacts).
- **Values** – where lack of environmental awareness (or antipathy towards these issues) leads to neglect of efficiency opportunities.

Source: POST (based on SPRU)

However, based on the analysis presented in Chapter 3 (Table 3.2), it is possible to identify which instruments are most likely to lead to incremental or radical innovation, and those that can help disseminate good practice. On this basis, it appears that an optimum 'mix' of instruments to encourage radical innovation in environmental technology might contain:

- **Regulatory instruments** such as standards that 'force' technology
- **Economic instruments** that place a 'price' on the use of the environment as a source of resources and as a place for waste disposal (e.g. tradeable permits)

- **Financial measures** such as support for industrial R&D
- **Networking measures** such as 'matchmaking' and best practice promotion.

Such a mix of policy instruments is seen by many as essential to create a step change in performance, and as suggesting that it should be used to encourage environmental improvement by firms at different stages of the process of moving from compliance to competitive advantage described in Section 2.1. For instance, the resources involved in regulation (such as IPPC) might be best targeted at those firms for whom basic compliance is itself difficult. Similarly, voluntary agreements might be most applicable for those firms who have taken up a compliance-plus stance; while economic instruments might be best suited to those companies who have gone beyond compliance-plus and have begun to seek competitive advantage from enhanced environmental performance. It is also worth bearing in mind that these instruments can be designed to complement each other.

The mix of instruments should also take account of the need to engage the supply chain, including final consumers, as it is here that many firms report market pressures are strongest. Finally, the mix should recognise that small and medium sized enterprises (SMEs) often find it difficult to innovate, but that they are not a distinct sector, and display a wide range of different characteristics (as well as just size), such as management attitudes towards the future beyond the short-term.

4.2.3 Creating the Policy Climate

4.2.3.1 The Policy Framework

A key aspect in stimulating innovation is that industry responds well to policy that reduces the risks they face. Policy should provide some indication of the direction that society wishes industry to follow in the longer-term, and offer coherence and stability in the instruments used by governments and regulators to reach that destination. Nevertheless, many have argued that environmental policies have tended to be developed and implemented as short-term reactions to crises, but that this is no longer adequate and that a more proactive approach to policy is required. This arises because it has become more widely recognised that technological progress is accelerating and becoming an ever more complex process, with many actors involved. Similarly, it presents many risks that can be highly pervasive and contentious. Under these conditions technological progress is no longer amenable to reactive regulation with limited scope.

For innovation in environmental technology to proceed many now argue that a **key requirement is the establishment of a long-term strategy that sets out targets for the reduction in the use of resources and the production of waste**. These targets, it is argued, would be supplemented by interim goals, and be based on quantitative indicators. Furthermore, any such strategy would include a timeframe for the targets (and interim goals), and be reviewed and updated regularly. One option, therefore, is for **the government to extend its 'sustainable development' strategy beyond that set out in**

"A Better Quality of Life[32]" to incorporate a range of targets based on indicators. It is necessary to recognise, however, that developing indicators and targets for some elements (e.g. resource use) poses considerable practical difficulties; not least in deciding which indicators to use in the first place. Nevertheless, indicators have been (or are being) developed in some areas, such as climate change, air quality and discharges to the sea.

4.2.3.2 The Role of Regulation

It has been increasingly recognised that the style of regulation matters as much as the regulation itself, so questions arise about the role of regulators in encouraging innovation in environmental technologies. Chapter 2 described the existing and new regimes for industrial pollution control (IPC and IPPC respectively), and shows that the bedrock of both approaches is the concept of best available techniques (BAT). The question was raised in that section over whether and how BAT could act to stimulate innovation in environmental technology. It was seen that, as set down in the IPPC Directive and draft regulations for the UK, BAT has been designed so that it does not act as a barrier to innovation, but that there are no specific requirements for it to be used a stimulus.

However, there are other possible approaches that depend heavily on the style adopted by the regulators (the Environment Agency for England and Wales and the Scottish Environmental Protection Agency) in their interactions with regulated industries. It has been widely acknowledged that the IPC regime (introduced in 1991) was a success and this has been attributed to the expertise and credibility of the regulators involved, and their ability to work closely with those they were regulating. In particular, the regulators played three key roles as:

- Agents for the active transfer of best practice – e.g. passing on their knowledge and experience of practical examples where one company had adopted new practices (such as substituting a less hazardous substance for another) that the inspector thought that other companies could also use
- Consultants to assist industry in developing and implementing their investment programmes. For instance, an inspector might see that a company was intending to move into a new business area in the next few years, and would be able to give advice on the best ways that environmental impacts of the new business might be minimised
- Enforcers of 'improvement programmes' through the setting of conditions on authorisations that existing techniques not representing BAT must be updated to comply with BAT within a fixed timescale.

It is intended that the new IPPC regime will be implemented along many of the same lines, although there are some questions about the ability and credibility of inspectors working in areas not traditionally within the realm of integrated pollution control (especially the food and livestock industries). IPPC in general (and BAT in particular) could be used as a stimulus for innovation, but the position of both the government and the regulators is that the new regime is not **intended** for this purpose, and so has no specific objectives along these lines. Nevertheless, both the government and the

[32] This was published in May 1999 (Cm4345) to set out the framework for action to deliver sustainable development in the UK. It does not put forward targets, but sets out progress against indicators.

regulators are keen for industry to move towards cleaner technologies rather than EOP solutions and would look to the necessary flexibility that the regulators will have in implementing the new regime as one way in which such a shift can be encouraged. Hence, it might be possible for an inspector, acting in a 'consultancy' role, to help a company to foresee where its environmental problems may arise in the future, and to suggest cleaner technological responses within an investment programme.

This possibility has not been explored in great depth, so one option is for **the regulators, the government and the devolved executives, to look into ways in which the IPPC regime can act as a positive stimulus for innovation in environmental technology, rather than relying on the regulations not acting as a barrier**.

Similarly, the IPPC Directive includes a provision that allows for the regulator to issue **general binding rules** for a particular class of industry, rather than tailor-made authorisations to individual companies. Such a move towards a sector-based regulatory system might allow regulators to establish BAT for entire sectors (rather than for individual processes), and so, with a system of frequent updating of the general binding rules, this could be a positive force for innovation. This aspect of the regulations has not been explored in great depth, so one option is for the **government and devolved executives to consider the role of the general binding rules provision of the regulations in acting as a positive stimulus for innovation in environmental technologies**.

One aspect of a shift to cleaner technologies that the regulatory system cannot deal with at present is the area of Integrated Product Policy (Section 2.4). It is very difficult (if not impossible) to police the entire life cycle of a product, and hence policy in this area would need to be developed on the basis of agreed product standards, voluntary agreements, labelling and economic incentives. In addition, such regulation (were it possible) might well inhibit innovation, for example by restricting localised experimentation and diversity in products. The issue of how to take forward IPP is outside of the scope of this current report, and is not considered further here.

4.2.3.3 Overview

Overall, it is essential to recognise the realities of how industry decides its priorities and investments (Table 3.2). Therefore, **activities aimed at promoting innovation should ensure that the technologies developed match the conditions for industrial application** – i.e. that they have the following characteristics:

- **Information** on economic and environmental performance is widely and easily available
- **Confidence** in their wider use built up from case studies of demonstrated performance
- The **managerial capacity** of the business is not stretched too much by the innovation – i.e. it should not be a great 'a leap of faith', nor should managers have to expend too much effort in making the choices
- The **technical capacity** of the business is not overstretched – i.e. there should not be undue pressure on staff to undertake technical aspects such as waste audits, life cycle assessments, process re-engineering, retraining and recruitment of specialised staff
- **Financial capital** should be readily available for innovative processes on terms that encourage risk taking where a high potential for benefits can be demonstrated.

The key to ensuring that innovations take account of the 'real world' is to ensure that the 'real world' actors (i.e. regulators, industry and other stakeholders) are fully involved in the process. This is discussed in more detail in the next section.

4.3 Research Needs

Cleaner technology as a concept is relatively new, and in many areas of the process industry, such innovations simply have not happened yet. If a move to the more widespread use of cleaner technologies in the process industries is to be encouraged, therefore, there needs to be considerable research and development in two main areas: science and engineering; and economics and management. Also, if such a shift towards cleaner technologies is acknowledged as the way forward for the medium to longer term, it raises questions about the strategy, organisation and funding of future research programmes in this area. Each of these is considered below.

4.3.1 Science, Engineering and Technology

The future development of environmental technologies for pollution prevention and control is inextricably linked with the future development of the process industry as a whole. Here, two influences are apparent - the process industry is increasingly required to become:

- More responsive to its customers needs – in particular through the development of smaller, more flexible, and locally-sited process equipment, and a business model based on supplying services based on manufactured products, rather than products *per se*
- More responsible with regard to its use of natural resources and the production of waste – in particular through improving resource efficiency, reducing waste at source, and substitution of less hazardous for hazardous substances.

The first influence is being driven mainly by the market, and the second by society as a whole. The Foresight Process Industry Group (FPIG) recognised these demands and saw that they can both be met if the process industry adopts a new approach whereby *"decentralised production in smaller, more environmentally acceptable and responsive process plant may be the best way to meet customers' needs"* (47).

To take this direction in the process industry, research and development of process plant generally, and cleaner technology in particular will need to address a wide range of scientific, engineering and technological issues, involving many academic disciplines. FPIG highlighted a number of overarching research needs, including:

- Processes and reactions taking place inside process equipment
- Physical properties of products, and how these provide the services required
- What happens to materials during processing
- Applying biological processing in a wider range of processes (beyond its current use in pharmaceuticals and food manufacture).

A more comprehensive attempt has been made by the Chemical Industries Association (CIA) to define its own research needs (66). These are outlined in **Box 4.2**. The CIA identified that the environment and sustainable development were a key motivation for innovation in many sub-sectors of the chemical industry. For the industry as a whole, then, it concluded that *"cleaner technology is an underlying driver for its competitiveness."* However, it also concluded that the *"development of cleaner technologies often requires cross-boundary activities if step-changes in performance are to be achieved... but [this] is often impeded by sectoral interests and funding mechanisms."* The CIA's position was that *"translating these recommendations into effective programmes of research and technology development will require a major change in the way in which government research funding policy is determined and implemented: The concept of partnership between government, industry and the academic community must be vigorously pursued."* This echoes the conclusion of FPIG that *"the research needed for the new process industry is very different from that which now feeds traditional technologies. R&D needs a revolution that is just as dramatic as that facing industry."*

BOX 4.2 CHEMICAL INDUSTRY RESEARCH PRIORITIES

In 1995, the Research Priorities Task Force of the Chemical Industries Association (CIA) Science, Education and Technology Committee identified 7 key social and economic factors affecting the chemical industry:

- People – including world population growth, increased life expectancy, and demographic changes
- Money – including the increasing mobility of capital and the movement of industry to the developing world
- Politics and trade – including the emergence of regional trade blocs, and instability at the margins
- Tolerance – including greater pollution reduction, tougher environmental legislation, and safer products
- Education – including the increased timescale of education and continuous education
- Work-patterns – including working time reductions, skilled maintenance replacing operators, globalisation and a drift from science and engineering
- Sustainable development – i.e. ensuring economic growth without environmental impacts.

Overall, 7 research priorities were identified:

- **Biotechnology** –biodegradable materials, biological synthesis of chemicals, biological treatment of wastes and the production of renewable resources
- **Catalysis** – synthesis of non-toxic substances, greater production efficiencies, less stoichometric chemistry (see section 2.4), lower environmental impact
- **Materials** – substitution and avoidance of toxic substances
- **Process –** waste and effluent treatment, emissions reduction and effluent control, process efficiency
- **Separations –** removal of waste materials and resources from process and effluent streams
- **Analytical –** in-line analysis and improved monitoring and understanding of environmental effects
- **Modelling –** improved prediction of the effects of chemical combinations.

The key areas that the Task Force identified were biotechnology and catalysis but it also suggested that materials science 'needed a boost' and that process technology needs chemical engineering input to develop integrated processes.
Source: (66)

4.3.2 Economics, Management and Policy

As well as developing the science, engineering and technology aspects of technological innovation, recent models of the innovation process have shown that it is also essential to understand economic and business management aspects. Thus, in the context of this report, it is necessary to gain a clearer understanding of the factors operating at firm and sector level that influence how industry might embark on a course toward adopting the new model for the process industry described in Section 2.4.

As discussed in Chapter 3 and outlined in Box 4.1, there are many drivers and barriers to innovation and investment in environmental technologies. Some are market failures, but many others are institutional and behavioural. However, there has been no attempt to collect comprehensive data on the extent to which the drivers and barriers affect technology choices within industry at the level of the individual firm, across sectors or across industry as a whole.

A key aspect of this 'data gap' is **the lack of information on the economic and environmental performance of cleaner technologies**. This arises because the process equipment providers are not easily identified, compared with the manufacturers of traditional EOP technologies (for whom there are highly visible trade promotion mechanisms). However, if realistic choices are to be made by firms, there needs to be a balance of information available. Furthermore, even collecting data on the use of cleaner technologies is difficult, because their deployment is rarely justified purely on environmental grounds. This contrasts starkly with EOP technologies, whose sole purpose is to meet environmental standards. Thus, while DETR's current survey of environmental expenditure identifies the relative expenditure on EOP and integrated processes, this accounts only for expenditure made where environmental protection is the main priority. As environmental protection can often be a by-product of the other benefits of cleaner processes (such as reduced costs and increased efficiencies), DETR's survey cannot provide a realistic picture of the balance between the use of EOP and cleaner technologies. This data gap needs to be addressed - one option is for the **DETR and DTI (possibly through JEMU) to consider ways of improving the visibility of cleaner, resource efficient technologies by collecting information on expenditure and motivation by industry**.

Finally, the role of environmental policy instruments in stimulating innovation in environmental technology also needs to be investigated more deeply. A key aspect here is the danger that instruments currently in operation (e.g. regulations, economic incentives, voluntary agreements and best practice and information dissemination) might be evaluated separately, with little coordination to identify which measures, and mixes of measures are most effective in improving environmental performance. Also, as integrated product policy develops, there is a need to examine and develop policy instruments that can take this forward. For instance, research is needed on the role that intellectual property protection can play in helping the transfer of knowledge of, and technology for, cleaner technologies between academia and industry. Similarly, further research is necessary on how the supply chain (and in particular, final consumers) can be harnessed to stimulate innovation and knowledge transfer.

4.3.3 Strategy, Organisation and Funding

There is a consensus emerging that the most cost-effective means of improving the environmental performance of industry in the medium to long-term is likely to be achieved using cleaner technologies, rather than EOP solutions (although EOP solutions will still be required to some extent[33]). This consensus has found voice within the government, with both the Secretary of State for Trade and Industry and Environment Ministers calling for industry to shift to this new model.

The Government's 1999 White Paper on Sustainable Development set out a vision for *"A Sustainable Economy"*, which included the need to increase resource productivity and to encourage the *"sustainable production and consumption of goods and services"*. In the White Paper, the Government stated that action is needed that is focused more directly on the production and use of goods and services. This, it stated, is based on achieving changes that involve:

- Continuous improvements in performance and extension of good practice
- Designing products so they can be easily upgraded and recycled
- New kinds of product and (in some cases) meeting consumer needs through services rather than goods.

To facilitate these changes, the government has adopted an approach ('**market transformation**') that works with the market and encourages entrepreneurship, using a mix of measures to:

- Give consumers better information and encourage purchasing initiatives which help move the market
- Promote environmentally-sensitive production by identifying indicators, setting targets and monitoring, promoting best practice, and supporting research and innovation
- Provide a supporting framework of information and investment programmes and, where appropriate, regulatory and fiscal measures.

Similarly, the White Paper states that the Government will encourage ways (such as Life Cycle Analysis – see Box 2.5) to look at environmental, economic and social impacts at all stages of a product's lifecycle, and will participate in the development of Integrated Product Policy. This is clearly a very wide agenda, beyond the scope of this report to cover comprehensively. Rather, the focus of this report is on the promotion of environmentally-sensitive production and how innovation can be encouraged in this area.

There are currently a number of policy instruments and government sponsored schemes in place to promote waste minimisation and eco-efficiency, but few aimed specifically at the development of cleaner technologies. In particular, the Clean Technology Programme managed by EPSRC has come to an end, and it is not yet clear how this to be taken forward. Suggestions have included setting up either a LINK programme or a Faraday Partnership (see Annex A, Box A1.2) but no decision has yet been reached. Similarly, the DTI has launched a 'Sustainable Technology Initiative' (STI), but again, the direction of this is not yet clear. The government also sponsors a number of LINK schemes with application to increased process efficiencies, and the Environmental Technology Best Practice Programme. This is about to enter a new phase, but its aims and objectives remain unchanged from the current phase. So it will continue to identify

[33] Both within a process, to assist in recycling, recovery and reuse of materials and also for the clean-up of residual waste streams.

and promote best practice in waste minimisation and cleaner technology. One aspect that is different in the new phase, however, is that there will be no R&D programme within ETBPP. This has effectively been amalgamated within the STI.

In a further initiative, the government recently set up an Advisory Committee on Consumer Products and the Environment (ACCPE), chaired by Dr Alan Knight, Environmental Policy Controller for B&Q. ACCPE's remit is to advise ministers on *”the development and coordination of policies to reduce the environmental impacts associated with the production and consumption of goods and services, and the priority areas for research and future action in these policy areas.”* In particular, in the context of this report, ACCPE will focus on “*tackling the major environmental impacts of products across their life cycle, taking into account developments at the EU level on integrated product policy*.”

Economic instruments that could provide incentives for innovation in environmental technology include tax credits for research and development, the landfill tax and the climate change levy, alongside voluntary agreements to reduce greenhouse gas emissions. The regulatory framework for industrial pollution prevention and control (IPPC) is not explicitly able to promote innovation, but it is not intended to be a barrier. Nevertheless, IPPC has been designed with a great deal of flexibility in mind – in particular over what represents the best available techniques (BAT) for pollution prevention and control. It is envisaged that much will be left to the discretion and judgement of the regulators themselves, so there are likely to be opportunities, at the operational level, to 'nudge' industry gently towards wider adoption of cleaner technologies.

Clearly, there are many activities currently in place that could act to stimulate the development and deployment of cleaner technologies. Nevertheless, the nature and scale of the challenge ahead should be borne in mind – leading many leading academics, industrialists and politicians to refer to this challenge variously as a 'paradigm shift' a 'reinvention' or a 'green industrial revolution'. Because of the scale of the changes required, some have called for a more positive commitment towards a dedicated programme of research and development that would aid market transformation to restructure industry around environmentally-sensitive production (i.e. through the use of cleaner technologies). The question arises, therefore, over **the extent to which the current mix of measures, policies and programmes under the umbrella of 'market transformation' is able to provide the necessary stimulus to innovation in environmental technologies for new forms of production**.

EPSRC is yet to decide how it is to carry forward the Clean Technology Programme. Progress has been modest to date under the 'Sustainable Technologies Initiative' (i.e. the objectives for the programme have been determined, but a scheme of work has yet to be agreed). These facts indicate that there is no coherent approach to the support for research and innovation into environmental technologies. This contrasts with activities in the USA and Germany. These countries are of particular relevance, as they are the market leaders in the supply of environmental technologies, and so an examination of their activities to stimulate innovation in environmental technology is useful.

In the USA, the Environmental Protection Agency (EPA) and the National Science Foundation (NSF) jointly fund a $5M per year programme entitled 'Technology for a Sustainable Environment'. This programme is founded on the premise that EOP technologies are *"not sufficient"* to create economic growth while sustaining the environment. It is an integral part of other initiatives run by the two organisations. In particular, the EPA funds research into 'green chemistry' and 'green engineering' and the NSF runs programmes in 'Environmentally Benign Chemical Synthesis and Processing' and 'Environmentally Conscious Manufacturing'. Also, the Office of Industrial Technologies of the US Department of Energy provides over $160 million per year in its Industrial Technologies Program. These initiatives are seen as part of an evolving '**research stewardship network**' in green chemistry and engineering, with joint actions between federal agencies, industry and academia forming the basis of a co-ordinated research strategy and network. The total level of funding for all research initiatives has not been published, but is likely to be close to $200 million per year.

In Germany, the Federal Research Minister announced (in October 1999) a new priority research programme *"Forschung für die Produktion für Morgen"* (Research for Tomorrow's Production). This 5-year, DM600 million (£200 million) programme will focus on advanced production systems and technologies, and aims to:

- improve the competitiveness of German industry
- promote environmentally-sensitive production processes
- support new ideas for further training and qualification of staff.

The question arises, therefore, of **how the UK should move forward in developing the support for research and innovation necessary to help the process industries shift to a more environmentally-sensitive basis**.

Three key elements would be necessary:

- **Strategy** – to define the objectives and scope of the innovation required, recognising the need both to 'get the science right' and to take full account of the business processes necessary to bring technologies to the market place. This would also identify the actors involved from government, regulators, research councils, academia, industry, consumers and other stakeholders.
- **Coordination** – to ensure that all actors are fulfilling their commitments, are working across traditional boundaries of academic disciplines and business sectors, while at the same time avoiding unnecessary overlap between actors and initiatives.
- **Funding** – the level of funding must match the commitment. It does not need to come from one source, however - a partnership approach is most likely to be successful in delivering the research effectively.

In moving towards a mechanism to achieve these objectives, several factors need to be borne in mind:

- The process industry sector is made up of disparate sub-sectors
- The structure of the sector and its sub sectors is variable – with firms of many different sizes, operating in different markets (e.g. both domestic and overseas)
- There are many different process steps within manufacturing

- Much can be done to move the process industry towards more environmentally-sensitive production (here, for instance, benchmarking of the performance of comparable processes across industry may be helpful)
- The process industry is supported by firms providing equipment and services such as reaction vessels, filters, water treatment, etc.
- Firms have different levels of technical and managerial expertise and resources
- There are many sources of funding for research and innovation, often with different objectives[34] and mechanisms, aimed at different parts of industry and academia, and often targeted at different phases of the innovation process (from 'proof of concept' through to support for pilot and demonstration projects).

In the process industry, the significance of the process steps varies between the different sub-sectors. For instance, process design is highly significant in the chemical industry, but less so in cement and lime manufacture. Also, the relevance of the activities that improve the environmental performance of production varies between the process steps. For instance, biological processing is highly relevant to process design and control, but less relevant to product handling. Taken together, the factors set out above lead to the situation where it is unlikely that a single research programme, funded from a single source will be able to account for the complexity inherent in the process industry.

The question arises, therefore, **how best to define a coherent and coordinated innovation strategy for environmental technology?**

There are a number of possible approaches to defining the strategy. Suggestions have included:

- A task force or steering group (e.g. at a recent Foresight ENE Panel workshop, there was a suggestion for a '**Sustainable Technology Task Force**'). This would comprise a broad range of members representing the actors involved. Such a body could be established within the framework of the Foresight programme; possibly as a thematic panel in its own right; or as a joint initiative of the Chemicals, Energy and Natural Environment, Materials and Food Chain and Crops for Industry Panels.
- An informal interdepartmental government group (comprising representatives from DTI, DETR, Treasury, MAFF, DfEE and representatives of the executives of the devolved assemblies) to act as an information exchange forum.
- An inter-agency committee, possibly comprised as above but with additional representatives from other public bodies with an interest in this area – such as regulators and research councils. It might also include members from industry (e.g. through representatives of Foresight panels), and other stakeholders such as Regional Development Agencies and environmental NGOs.
- An independent advisory group. This could exist as a stand-alone committee, or as a sub-committee of the newly established Advisory Committee on Consumer Products and the Environment which has the remit (among other things) to advise on *"the priority areas for research"*.

[34] E.g. building partnerships between industry and academia (LINK), focusing education and training (e.g Postgraduate Training Partnerships); or facilitating technology transfer (e.g. the Clean Development Mechanism under the Kyoto protocol to reduce greenhouse gas emissions – see forthcoming POST report on this topic).

Whichever mechanism is adopted, the terms of reference for developing a strategy might include:

- Reviewing current and planned activities in this area in the UK and elsewhere (e.g. the European Union, the USA, Germany and Japan).

- Identifying areas of duplication, overlap and omission. Part of this would address whether it would be most effective to establish programmes specifically for environmental technology, or whether these should be integrated within other programmes. Here, a dilemma arises. A separately funded programme runs the risk that many industrial sectors and researchers would see environmental technology as a sideline issue with little relevance to their own interests. On the other hand, integrating the concept into mainstream disciplines and sectors, runs the risk that environmental technology would receive less attention and not be strongly 'championed'. A third alternative, of course, is that both approaches are adopted and a 'suite' of programmes is developed.

- Developing a **national strategic framework for innovation in environmental technology**, which would set out:
- The definition of 'environmental technology'. In particular, making it explicit that this includes cleaner products and processes, unlike the traditional definition which tends only to concentrate on end-of-pipe clean-up technologies.
- The objectives for a national strategy – to protect the environment from pollution; conserve natural resources; develop and maintain strong academic and industrial innovation; and to enable industry to compete in the emerging world-wide market for resource efficient products and process technologies.
- The major areas for research, development, demonstration and dissemination and marketing necessary to ensure the objectives are met. These would include both scientific, technological and engineering aspects, as well as those related to economics, management and policy.
- The means for implementing the strategy. This would need to take account of the variety of funding sources; the structure and complexity of industry; the applicability of resource efficiency to different products and processes; the desirability of specific or integrated innovation programmes (or both); and the need for interdisciplinary, cross-sectoral and international working.

The opportunity arises therefore, for **the government and the devolved executives to consider the most effective means of developing a coordinated national innovation strategy for environmental technology**.

Clearly the next stage would be to implement the strategy. Without pre-empting any conclusions, however, it appears at this early stage that, given the complexity and breadth of scope involved, **a suite of funding sources may be a suitable approach; coordinated by an umbrella body of some form to ensure coherence and effectiveness**.

4.4 In Conclusion

Around the world, industry in both developed and developing countries faces many pressures. Innovation has been identified as the key to success in many areas. Not least among these is the need to improve environmental performance. As industry generally, and the process industry in particular, adapts to the knowledge based economy, huge commercial opportunities arise in the global market to implement a new model based on innovative industrial processes that combine increased efficiencies, flexibility, responsiveness and environmental performance. This has been described as a 'green industrial revolution' - a vision backed by many in international organisations, government, academia, industry and NGOs.

To take this vision forward in the UK, however, there would be a number of key requirements:

- **A stable policy climate that provides a long-term vision for environmental performance in accordance with the principles of 'sustainable development'.**
- **A policy framework comprising a mix of instruments designed to maximise the opportunities for innovation in large and small companies across a wide range of sectors operating in domestic and overseas markets.**
- **A coordinated and well-resourced national strategy for innovation in environmental technologies**

Recent government statements on the importance of innovation and on reducing the environmental impacts of production and consumption, and the imminent implementation of a new regime for industrial pollution regulation, provide opportunities to debate and develop national strategies in this area. The Parliamentary Office of Science and Technology hopes that this report will be useful to Parliamentarians and others in this regard.

ANNEXES

ANNEX A THE PROCESS OF INNOVATION

Innovation does not proceed along a linear chain from basic research, through applied research, into development and production and then into the sale of products in the marketplace. Rather, the key to successful innovation is a structure of efficient networks. Links should exist at all stages and in all directions to facilitate the transfer of information, formal knowledge and tacit understanding. Constituents of effective innovation networks will include industry, research institutions (particularly universities), government and sources of capital investment.

A1.1 Industry – Academia Links

It is widely recognised that the UK has a world class science, engineering and technology research base. However, it is often perceived that the UK is less successful at exploiting this. **Box A1.1**. outlines some of the barriers to successful innovation.

A key to overcoming these barriers is to build strong links between Higher Education Institutions (HEIs) and industry. These links provide a transfer of knowledge and highly skilled workers to industry but are also of benefit to the HEIs themselves. The **benefits** to a HEI include new areas of research/training, opportunities to apply research work, increased funding, and a raised profile.

However, it is important that both sides of any linkage should receive the benefits without having to forego their **values.** An industry-academic linkage can be in keeping with the values of a HEI because it can be used as a research activity or an opportunity to influence business while also strengthening the position of the HEI in society. This may require both sides of the linkage to alter their behaviour to benefit fully, but this should not involve a compromise in the values of the institutions. If the behaviour of industry and HEIs is adjusted to allow common aims and methods to be found, the strength of the innovation network should increase substantially. A continuous flow of ideas in all directions is desirable and necessary. It is also important to encourage Small and Medium Enterprises (SMEs) to form the same style of linkages as their larger counterparts. The government operates a number of schemes to encourage industry and academia to collaborate, described in **Box A1.2**.

A1.2 The Industry-Finance Linkage

Access to appropriate finance is vital for all long-term investment, of which innovation is an important part. Establishing a link between potentially innovative firms and reliable sources of funding is therefore highly desirable. The link between companies and the capital necessary for innovation is more applicable to SMEs than large companies, who often have the potential to finance their own innovation. Money is required at all stages of any innovation process, and any discontinuity in the funding process will disrupt the innovation network. **Box A1.3** describes a range of potential sources of funding.

BOX A1.1 BARRIERS TO INNOVATION

Innovation Culture - An 'innovation culture' is built up of many attitudes and types of behaviour, many of which are far from cultural. One of the key cultural explanations of innovation failure is an unwillingness to take risks. The willingness of investors to do so is determined by institutional factors such as fear of the consequences of bankruptcy and availability of credit. It is over simplistic to say that the UK does not possess the necessary culture for successful innovation. Radical innovation entails large risks, but also gives greater average rewards than other investment if it succeeds.

Legal Framework - To encourage innovation, the legal framework needs to support risky investment and confidential research. Concerns about bankruptcy are likely to limit the actions of would-be entrepreneurs with innovative intentions, but bankruptcy laws do not consider entrepreneurship and allow for mistakes made through risky investment. The DTI has announced plans to change bankruptcy laws to remove the stigma on those whose businesses fail through circumstances beyond their control, despite their best efforts

Macroeconomic Conditions - Economic stability is required to enable long term plans to be made in research and in investment. Inflation, demand fluctuations and budget deficits hamper the long-term planning necessary for innovation. High interest rates will increase the cost of finance and hinder innovation. Also, companies are unlikely to fund research, as the results may come too late to make it profitable.

Management of Company Priorities - Effective research and development by companies has been shown to generate substantial, usually long-term, profits. It is a vital part of the innovative process, performing strategic and applied research that may not be the priority of HEIs. To fund R&D, companies need long-term vision. Management goals based upon short-term success with consumers will be detrimental to innovation networks. While in the short term the market creates innovative opportunities for exploitation, in the long term the market is determined by the behaviour of innovative companies. Long term, radical, innovation breaks the mould and creates markets, while short-term management goals will destroy real innovation. From the opposite perspective, it is just as important for companies to maintain a market focus while researching.

The Acceleration Trap and the R&D Race - Consider a line of products made by a company as being contained in a hose. R&D provides new products to push in the end of the hose while obsolete products fall out at the other end. Increasing R&D provides more products to push down the hose while, at the other end, products become obsolete at the same rate as before, causing pressure on older products. Eventually, products are forced out of the hose at the new rate and the flow through the hose speeds up. Acceleration cannot keep increasing, so revenues must eventually decline. Increasing R&D has reduced the life cycle of products and the company is stuck with high R&D spending levels. Faster innovation looks attractive because of initial benefits such as growth in sales. These do not persist however, as innovation rates cannot increase indefinitely. The Acceleration Trap feigns growth by presenting companies with sales that would have been realised at a later date in any case. This will shorten industrial time horizons and lead to more innovation failure and less chance of finance for riskier R&D. If innovation is competitive, a situation can arise that is much like an arms race. Action is replaced by constant reaction and no player can win. There is a tendency to overdevelop products unnecessarily for the sake of one-upmanship. In this sense, innovation occurs at too great a rate for customers to reap its benefits. Because of the long-term nature of R&D expenditure, there is always commitment to a budget, which prevents retreat. Based upon these points about the R&D process, the implication is that the key R&D decisions rest upon what, not how much, to put into the product hose.

Lack of Awareness of Government Support - For the government to encourage innovation actively and effectively, via funding schemes etc., it is vital that firms (especially SMEs) and HEIs know what is available and what is suited to their needs. The DTI has attempted to simplify the maze of available schemes, and while a one-stop-shop for innovation schemes is unlikely, information could be more centralised and more widely advertised. The DTI's "Innovate Now" web site has contributed in this area.

Regulation - This can be either a barrier or a stimulus for innovation. To be efficient, innovation networks should not be hampered by cumbersome regulation, and ideas, products, processes and people should be able to flow freely. In some instances, however, it appears that regulation has forced the hands of innovators in highly beneficial ways. Regulation can create a useful incentive structure for firms to innovate and it can force firms to increase innovation efficiency.

BOX A1.2 COLLABORATIVE SCHEMES FOR INDUSTRY AND ACADEMIA

The **LINK** scheme, set up as part of the Foresight programme and run by the Office of Science and Technology, encourages collaborative research between the science and engineering base and the users of research in industry. LINK projects receive up to half of their funding from research councils and the government, with the remainder being provided by industry. LINK projects address the priorities of the government's Foresight Programme.

The Innovative Manufacturing Initiative (IMI), managed by the Engineering and Physical Sciences Research Council (EPSRC) as part of the LINK scheme, encourages process-based innovation in manufacturing, particularly from a management perspective. According to the EPSRC, there has been success in attracting industry, perhaps more so than that of the LINK scheme itself.

Faraday Programmes aim to help address the discontinuity in funding arrangements between the early (basic and strategic) and later (applied) aspects of research. The programmes are based around the Fraunhofer scheme in Germany. Partnerships are set up between Industrial Research Organisations and the science and engineering base to encourage flows of technological knowledge and skilled people in either direction. Faraday Centres, based around intermediate research institutions, facilitate these partnerships. The first four programmes were announced in July 1997, and were reviewed last year. Plans for further programmes have been outlined in the government's Competitiveness white paper.

Collaborative Awards in Science and Engineering (CASE) are doctoral-level projects involving academic and industrial research supervisors. A CASE student must spend three months of the three-year award working for the company in question.

Postgraduate Training Partnerships (PTPs) connect HEIs with Industrial Research Organisations (IROs). Students conduct academic research at the IRO while under university supervision. The aim is to expand the horizons of the IRO and boost its ability to transfer technology to industry. PTPs were conceived as part of the Faraday concept.

The **Teaching Company Scheme (TCS)** gives graduates the opportunity to work in industry and introduce new technology with academic supervision. This is a good example of a two-way link, providing industry with direct academic input and graduates with industrial experience.

A1.3 Networks Between Businesses - Corporate Venturing

In the last decade, the context of innovation has been changed by the increasing degree of collaboration between businesses. This can, for instance, take the form of shared R&D or an exploitation of 'collaborative advantage' (**Box A1.4**). This is based on the idea that few companies 'have what it takes' to create, enhance and market complex, innovative products on their own. Consequently, innovation is envisaged as collaboration between businesses with common aims, rather than competing with a large, existing firm. Corporate venturing is becoming an important way of ensuring that innovation can continue, as large companies often find it difficult to generate new ideas, while SMEs can generate ideas more easily, but have too few resources to exploit them. Partnership between large and small companies, then, is one way to ensure that large companies get access to ideas, and small companies get access to money.

BOX A1.3 GOVERNMENT AID TO FUNDING INNOVATIVE PROJECTS IN SMEs

Small Firms Merit Award for Research and Technology (SMART) is a competition run by the DTI where small firms submit proposals for a maximum £45,000 grant to contribute up to three quarters of the costs for a feasibility study. SMART now encompasses **Support for Products Under Research (SPUR)** is intended as a follow-up to SMART, and is for SMEs developing projects involving significant technological advances. Each project is judged on its own merits and the maximum grant of £150,000 is designed to contribute up to 30 per cent of the project cost. A higher-level form of SPUR (SPUR-plus) gives a maximum grant of £450,000 for projects leading to a nation-wide technology improvement.

The Small Firms Loan Guarantee Scheme (SFLGS) allows small firms with little security or innovative past to obtain business loans from banks. The DTI provides security for up to 70 per cent of the loan for new businesses and 85 per cent for existing businesses. Borrowers pay in return a premium of 1.5 per cent to the DTI.

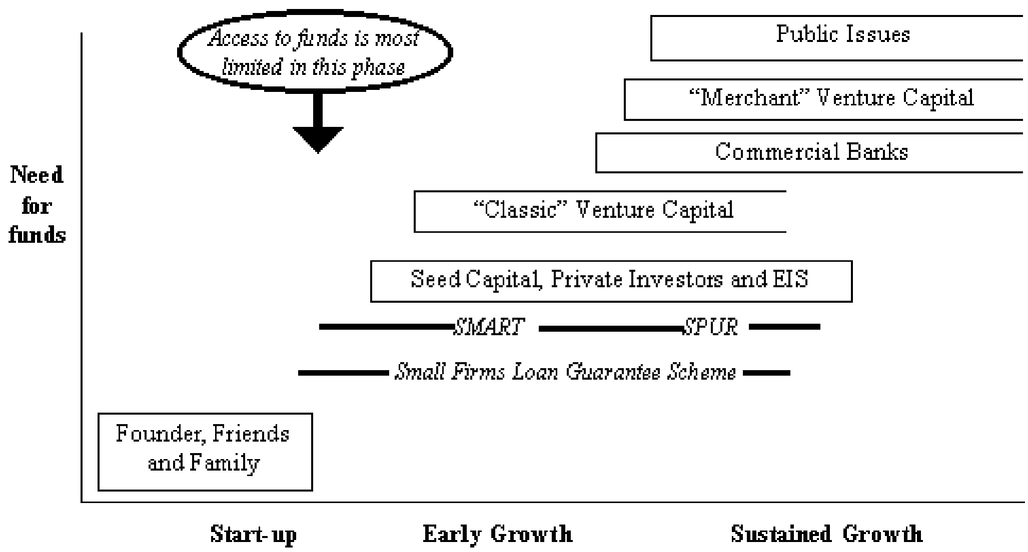
Seed capital is targeted at firms in the early stages of development. Because of the inherently uncertain nature of the firm's development, seed capital providers tend to favour a "hands-on" approach to their investment.

Venture capital is targeted at developing or starting firms with definite growth potential. **"Merchant" venture capital** is targeted at more established firms for management buy-outs and buy-ins. This form of capital now dominates the UK venture capital market.

The **Enterprise Investment Scheme (EIS)** relates to investment in unquoted, often small companies. Unquoted companies can raise up to £1 million a year and individuals can invest up to £100,000 a year. Shares must be retained for a minimum of five years, giving firms the benefits of long-term investment.

Business Angels, wealthy individuals with business experience, can be vital in bridging the 'equity gap.' They may also be connected with venture capital companies who may be willing to take over financing a growing, innovative firm after the 'equity gap' is crossed. Business angels are often more willing to take risks than venture capitalists, as they are investing their own money. Their presence is therefore important for a successfully innovative economy.

FIGURE FUNDING STREAMS FOR INNOVATION IN INDUSTRY

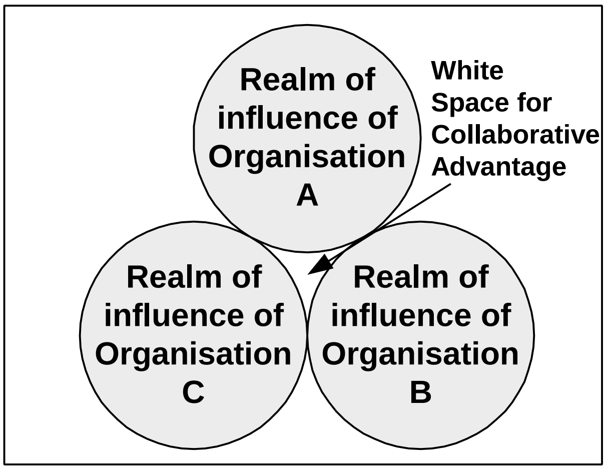


Source: (67)

BOX A1.4 "CREATING COLLABORATIVE ADVANTAGE"

The approach used by the Centre for Exploitation of Science and Technology (CEST) combines organisations to create collaborative advantage, bridging what it calls the 'innovation gap.' The innovation gap arises because of the inefficiencies of the innovation market, which in turn arise from a lack of perceived common aims and ideas. Collaborative advantage is gained when organisations (not necessarily businesses) acting together, achieve a result which could not occur if they acted individually. CEST's role is really to explore business opportunities related to innovation by congregating stakeholders around areas of unexploited possibility – what CEST refers to as the White Space Concept (see Figure).

FIGURE THE WHITE SPACE CONCEPT OF COLLABORATIVE ADVANTAGE



CEST's approach is that the White Space concept allows for quicker and more specific innovation than schemes such as those outlined in Box A1.1. When collaborative advantage has been obtained, there is then opportunity for competitive advantage for the participating individuals. CEST's approach is founded on the network/system model of innovation, with a focus on the whole rather than separate institutions or occurrences. The view of innovative competition, within the context of collaboration, is more effective than seeing innovation as a struggle based on competitive secrecy.

ANNEX B R&D IN ENVIRONMENTAL TECHNOLOGIES

B1 Government Departments

Environmental Technology Best Practice Programme (ETBPP). This programme is jointly supported by the Department of Trade and Industry (DTI) and the Department of the Environment Transport and the Regions (DETR). Its aims are to promote better environmental performance and to increase the competitiveness of British Industry through good practice in waste minimisation at source (which may involve end-of-pipe [EOP] technologies, but primarily by increasing resource efficiency) and the adoption of cost-effective cleaner technologies. Its latest phase is due to begin to wind down in April 2000, but a third phase has been announced, and is expected to run until 2007. Previous phases of the ETBPP had allowed R&D on an *ad hoc* basis, but this has been removed from the scope of Phase 3 – see below.

'Sustainable Technology Initiative' (STI). In April 1999, the government announced its intention to set up the STI to the tune of £7.8M over 3 years to 2002. The details of the programme are currently being developed, and current thinking is that there will be a LINK programme (see below) jointly supported between DTI and the Engineering and Physical Research Council (EPSRC) concentrating on an integrated approach to the design and manufacture of products. The STI will not specifically fund research into developments in EOP technologies. Similarly, STI will not fund the development of pilot-scale technologies or demonstration projects.

LINK. This is administered by DTI to develop collaboration between academia and industry. 50% of a project's funding is available from DTI, but the other 50% must be provided by industry. Five elements of the LINK programme have some connection with environmental technologies: Waste Minimisation through Recycling, Reuse and Recovery (WMR3) – see below; Surface Engineering; Sensors and Sensor Systems; Applied Catalysis and Catalytic Processes (ACCP); the Innovative Manufacturing Initiative (IMI).

Foresight LINK. This is an awards scheme that supports collaborative research projects between business and research base organisations. It provides opportunity for new technologies to be explored with a view to enhancing competitive success for business in current and new markets

Bio-Wise. DTI launched this programme (£13 million over four years) in January 1999 (to build on its previous Biotechnology Means Business [BMB] Programme). Its aim is to enhance UK industry's competitiveness and 'sustainability' through knowledge transfer and uptake of biotechnology. While strictly it does not fund R&D *per se* the programme aims to increase awareness, technology transfer and implementation in the biotechnology sector. One aspect of this is the Demonstrator Project Competition, where up to 25% of the total eligible costs are available to fund demonstration plants in areas that have the potential to further the commercial use of biotechnology. The scope of BioWise is being developed at present. Much of the focus its predecessor, the BMB programme, was on the use of biotechnology in EOP techniques – e.g. effluent treatment, organic waste treatment and odour controls, with little effort in exploring the scope for biotechnology.

Alternative Crops Unit (ACU). The Ministry of Agriculture, Fisheries and Food (MAFF) operates the ACU to help research, develop and implement the use of crops for things other than food. Examples include the growing of hemp for industrial fibres. Also, crops can provide an alternative to petrochemicals as a source of raw materials and feedstocks – e.g. the development of straw-based paints.

B2 Research Councils

Clean Technology Programme (CTP). In the late 1980s, the (then) Science and Engineering Research Council and the Agriculture and Food Research Councils established the CTP. The driver behind the programme was a realisation that EOP techniques were inherently limited in their ability to tackle the full range of environmental impacts from industry. In 1994, the Research Councils were reorganised. The CTP aspects of SERC went to the EPSRC, while those of AFRC transferred to the Biotechnology and Biological Sciences Research Council (BBSRC). However, BBSRC withdrew from the programme. Examples of programmes carried out under the CTP included Sustainable Cities; Cleaner Synthesis (jointly with EPSRC's chemistry programme) and Waste Minimisation. EPSRC is currently developing the scope of a follow-up to the CTP. Current thinking is to establish a LINK programme (see above) in 'sustainable' technology, which may merge with the DTI's STI (see above).

Waste Minimisation through Recycling, Reuse and Recovery (WMR3). The focus of WMR3 is research aimed at the development and implementation of cost effective technologies for recycling, re-use and recovery of materials within industry. Funding is available through the LINK programme (i.e. from DTI and EPSRC) or directly from EPSRC. The programme is connected to EPSRC's Materials Programme, where research aimed at materials usage, selection and disposal 'from cradle to grave' is a key priority. The principle underlying the topics in WMR3 is that *"it is more efficient to deal with waste as close to its source as possible, and before it is mixed with other waste. End of pipe systems will only be considered where the waste is recycled into the manufacturing process or the facility"* (68). The WMR3 programme does not include research aimed at avoiding the production of waste in the first place.

Engineering and Process Technology. This is a theme within the Engineering and Biological Systems key research area of the BBSRC. In the context of environmental technologies in the process industries, this includes: the Bioprocessing Engineering Programme, the Biocatalysis Programme and the Bioprocess Innovation aspect of the Innovative Manufacturing Initiative.

Global Environmental Change Programme. This is a programme of the Economic and Social Research Council (ESRC). The programme was launched in 1991 with funding of £15 million (making it the largest programme of social science research ever run in the UK). The programme supports a diverse body of social and economic research, much of which has implications for environmental technology. The programme divides into 5 key topic areas:

- Attitudes and social behaviour (e.g. perceptions of the environment)
- Environmental policy (e.g. institutions, procedures and economic and financial dimensions)
- Sustainability and Resource Management (including concepts of resource management)
- Business and the Environment (environmental management, technology and life cycle analysis and interactions between business and policymakers)
- International issues (e.g. international cooperation and globalisation)

B3 The Government Foresight Programme

B3.1 The First Round, 1994-1999

This initiative was announced in the 1993 White Paper on Science, Engineering and Technology. Its aim was to bring together industry and academia to identify opportunities in markets and technologies likely to emerge during the next 10-20 years, and the investments and actions necessary to exploit them. The process was facilitated by the DTI and implemented through the work of 16 independent Panels[35]. Technology Foresight identified a number of generic priority areas, each of which was assigned one of three levels of priority: Key (K), Intermediate (I) and Emerging (E). The priority areas, and their priority levels are shown in **Box B3.1**.

As can be seen in the Box, many of the generic priorities related to environmental technologies. The main areas of work on this topic conducted by particular Panels included:

- **Natural Resources and the Environment Panel** – Among its recommendations (70), the Panel suggested that investment is required in the "*widespread use of life cycle evaluation and management, and eco-design principles and practice studies*" and in "*clean, cost-effective sustainable technologies.*" Sub-Panels were set up on Cleaner Technologies and Processes (8) and Innovation (2). They both concluded that cleaner technologies, techniques, products and services offered opportunities for UK industry, but that further innovation is needed to enable this potential to be fulfilled. The panel also commissioned a study of 'Environmental Futures' (**Box B3.2**)
- **Chemicals Panel** – The panel concluded (71) that the future of the chemicals sector "*will be based on growth from the established community strengths, with research and innovation providing cleaner and more efficient processes, and higher added-value products. Increasing interdisciplinarity, combined with high quality basic and applied research will benefit existing industry and generate new avenues of opportunity, increasingly on a global scale.*"
- **Manufacturing, Production & Business Processes Panel** – the Panel identified (56) that processing technology must adapt to new criteria recommended that "*materials and processes must economically meet the growing demands for environmental compatibility*" and

[35] The make-up of the Panels changed over time, but by the end of the process, the Panels were: Agriculture, Horticulture and Forestry, Chemicals, Construction, Defence and Aerospace, Energy, Financial Services, Food and Drink, Health and Life Sciences, Natural Resources and the Environment, IT, Electronics and Communications, Leisure and Learning, Manufacturing, Production and Business Processes, Marine, Materials, Retail and Distribution and Transport.

that *"processes need to be low cost, low energy, low waste, rapid and flexible"*. Also, *"materials must be suitable for efficient disposal or re-use at the end of their primary application."*

BOX B3.1 GENERIC PRIORITIES FROM TECHNOLOGY FORESIGHT

1. Social Shaping and Impact of New Technology
- Effects of demographic change on financial services, leisure, learning etc. (E)
- Risk assessment and management and applications in finance, food, health, travel and the environment (I)
- Work, place and home, including the social acceptability of new technology and the impacts of new technology on work and leisure (I)

2. Harnessing Future Communications and Computing
- Communicating with machines, including virtual reality applications, image analysis and interfacial software (K)
- Design and systems integration (I)
- Information management (I)
- Modelling, simulation and prediction of complex systems (from product design to environmental modelling) (I)
- Optical technology (e.g. displays, storage and communications) (K)
- Software engineering (including safety critical systems) (K)
- Telepresence (e.g. tele-learning, tele-working and tele-medicine) (K)

3. From genes to new organisms, processes and products
- Bio-informatics (gathering and processing basic biological data) (K)
- Bio-materials (e.g. biocompatible materials and self-assembly of complex materials) (I)
- Genetic and bio-molecular engineering (drugs, proteins, etc.) (K)
- Health and lifestyle (including diet, preventative health and fitness) (K)

4. New materials, synthesis and processing
- Catalysis (I)
- Chemical and biological synthesis (chemicals, energy and food) (I)
- Materials (I)
- Materials processing technology (I)

5. Getting it right: precision and control in management
- Management and business process engineering (K)
- Automation (E)
- Process engineering and control (I)
- Sensors and sensory information processing (K)
- Security and privacy technology (K)

6. A Cleaner World
- Clean processing technology (E)
- Energy technology (E)
- Sustainable technology (K)
- Product and manufacturing lifecycle analysis (E)

Source: (69)

- **Materials Panel -** The materials panel recommended (73) that there should be higher investment by the public and private sectors in *"materials and processes that improve the environment."*
- **Foresight Process Industry Group-** The MPBP and Chemicals Panels asked the Group to investigate possible future scenarios for a range of process industries (47). The major conclusion of its studies of the consumer products and bulk chemicals sectors was

that *"there is a growing emphasis on customer needs, rapid time to market and improved environmental performance. A natural consequence of these factors is that process plant will be smaller, nearer to customers, more responsive and with a very much reduced environmental impact."*

B3.2 The Current Round

This is the name of the new 'round' of Foresight[36], launched in April 1999. The Panels have been reorganised[37]. In relation to environmental technologies, the following activities are relevant:

- **The 'Sustainable Development' underpinning theme** – This is currently being developed, and has not yet published any material related to environmental technology.
- **The Manufacturing 2020 cross-cutting panel** – The Panel was launched in September 1999 and is due to report in November 2000. It aims to cover three main areas: technology issues (examining today's embryonic technologies to see what threats or opportunities they may present by 2020); supply chain issues (identifying potential developments in supply chain management); and development of a Foresighting Facilitation Pack (FFP) which will help companies of all kinds develop their own tools to embed Foresight-style thinking in their strategies (41).
- **The Energy and Natural Environment (ENE) Panel** – This is a new Panel and is only just deciding its own priorities and actions. A workshop was held towards the end of 1999 to identify a range of ideas that it might carry forward. Although an action plan has yet to be agreed, one suggestion was for a Foresight Task Force on 'Sustainable Technologies' that would comprise members from the ENE, Chemicals, Materials and Manufacturing Panels.
- **Chemicals Panel** – The aims of the Panel are to "improve the ability of the UK chemicals sector and its associated domestic and global supply chains, to secure and sustain incremental wealth in the UK, and improve the quality of life in a environmentally-sensitive manner across the globe" (75). The Panel is in the process of developing its action plan. However, it expects to focus on a number of issues, including "*the increasingly intense societal, regulatory and other constraints on industrial processes and products and the consequent need for industry to adapt and innovate.*" The panel intends to interact closely with other Panels, particularly the Manufacturing 2020 Panel.
- **Food Chain and Crops for Industry Panel** – One area on which this Panel will concentrate is the future of industrial crops. This explores the idea that most of the chemical processes which today rely on fossil raw materials could be carried out in crop plants with enormous potential benefits for the environment, and that crop plants could also be used to make high value products (76).
- **Materials Panel** – It is a specific aim of the Panel to establish task forces to report on emerging technologies and sustainability issues, especially those which involve other panels (77).

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[36] The initiative is no longer called Technology Foresight.

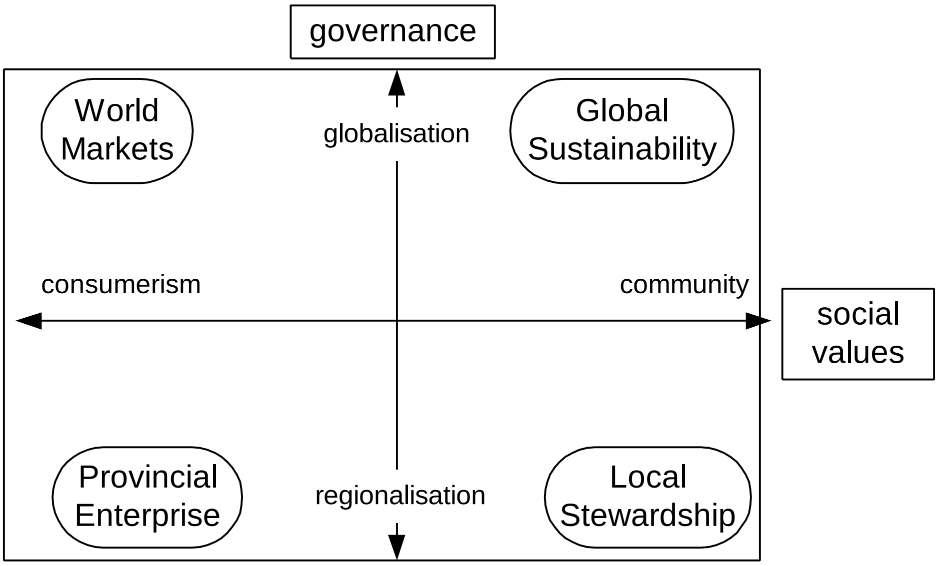
[37] There are now 10 Sectoral Panels (Built Environment and Transport, Chemicals, Defence, Aerospace and Systems, Energy and Natural Environment, Financial Services, Food Chain and Crops for Industry, Healthcare, Information, Communications and Media, Materials, Retail and Consumer Services). There are also 3 Thematic Panels (Ageing Population, Crime Prevention and Manufacturing 2020), and 2 Under-Pinning Themes (Education, Training and Skills and 'Sustainable Development').

BOX B3.2 THE FORESIGHT ENVIRONMENTAL FUTURES SCENARIOS

A team from the Science Policy Research Unit , the Silsoe Research Institute and the University of Leeds Institute of Transport Studies was commissioned by the Foresight Natural Resources and the Environment Panel to develop four scenarios that describe Britain in the period 2010-2040. The scenarios are not intended to predict the future, but to highlight current choices, given possible futures. They set out potential futures, exploring alternative directions in which social, economic and technological changes may evolve over the coming decades. The scenarios have been framed in relation to social values and governance systems (see Figure). The four scenarios are:

- **World Markets** – a world defined by emphasis on private consumption and a highly developed and integrated world trading system
- **Global Sustainability** – a world in which social and ecological values are more pronounced and in which the greater effectiveness of global institutions is manifested through stronger collective action in dealing with environmental problems
- **Provincial Enterprise** – a world of private consumption values coupled with a capacity for lower level policy-making systems to assert local, regional and national concerns and priorities
- **Local Stewardship** – a world where stronger local and regional governments allow social and ecological values to be demonstrated to a greater degree at local level

FIGURE THE ENVIRONMENTAL FUTURES SCENARIOS



The implications for environmental technologies under each of the scenarios would be:

- **World Markets** – 'sustainable development' and the environment are low priorities. Innovation is rapid (based on IT and biotechnology). Manufacturing industry declines, and innovation in environmental technology is driven only by cost-savings.
- **Global Sustainability** –'sustainable development' and the environment are fully integrated into policy. Innovation is rapid with manufacturing industry based on clean, low-input production and consumption.
- **Provincial Enterprise** - 'sustainable development' and the environment are very low priorities. Innovation is slow, and investment in eco-efficiency and waste management is low.
- **Local Stewardship** - 'sustainable development' and the environment are fully integrated into policy. Innovation is slow but industry has restructured to be smaller, and hence manufacturing processes have become smaller and more eco-efficient. Products are more durable.

Source: (74)

B4 European Union Fifth Framework Programme

The Fifth Framework Programme (FP5) sets out the priorities for the European Union's research, technological development and demonstration (RTD) activities for the period 1998-2002. These priorities have been identified on the basis of a set of common criteria reflecting the major concerns of increasing industrial competitiveness and the quality of life for European citizens.

The Fifth RTD Framework Programme differs considerably from its predecessors. It has been conceived to help solve problems and to respond to major socio-economic challenges facing Europe. The Fifth Framework Programme has two distinct parts: the European Commission (EC) framework programme covering research, technological development and demonstration activities; and the Euratom framework programme covering research and training activities in the nuclear sector. A budget of 15 billion Euros has been agreed for the period up to the year 2002 of which 13.7 million Euros is for the implementation of the European Community section 1.3 billion Euros have been allocated to the Euratom programme.

To maximise its impact, it focuses on a limited number of research areas combining technological, industrial, economic, social and cultural aspects. A major innovation of the Fifth Framework Programme is the definition of 23 '**Key Actions**' spread across four Thematic Programmes (**Table B4.1**). These are designed to mobilise the wide range of scientific and technological disciplines - both fundamental and applied - required to address a specific problem. It is intended this will overcome barriers that may exist, not only between disciplines, but also between the programmes and the organisations concerned. In addition to the Key Actions, each Thematic Programme includes Generic Activities and Support to Research Infrastructures.

The area of the programme most relevant to environmental technology is the Competitive and Sustainable Growth Thematic Programme, and within that, the Innovative Products, Processes and Organisation Key Action. Here, a budget of 731 Euros has been set down (representing 27% of the total for the thematic programme). This Key Action has four research objectives:

- **Efficient production, including design, manufacturing and control** – the aim is *"to develop European approaches for improved competitiveness, by enhancing industrial output in product/service combinations through innovative technologies, development of increased added value, quality, responsiveness to market and reduced time-to-market, and material content."*
- **Intelligent production** – The aim is *"to optimise the level of performance (improved quality, minimisation of resources) of all elements of the European industrial environment through deployment, integration and application of innovative technologies."*
- **Eco-efficient processes and design** – The aim is *"to develop and validate global approaches to minimise full life cycle impact of processes and products/services."*

TABLE B4.1 FP5 – THEMATIC PROGRAMMES AND KEY ACTIONS

THEMATIC PROGRAMME	**Budget** (millions Euros)	**% of total budget**	**THEMATIC PROGRAMME**	**Budget** (millions Euros)	**% of total budget**
Quality of life and management of living resources	**2413**	**16%**	**Energy, environment and 'sustainable' development**	**2125**	**14%**
Key Actions: • Food, nutrition and health • Control of infectious diseases • The "cell factory" • Environment and health • 'sustainable' agriculture, fisheries and forestry, and integrated development of rural areas • The ageing population and disabilities	1860		Key Actions: • 'sustainable' management and quality of water • Global change, climate and biodiversity • 'sustainable' marine ecosystems • The city of tomorrow and cultural heritage • Cleaner energy systems including renewables • Economic and efficient energy for a competitive Europe	1921	
User-friendly information society	**3600**	**24%**	**Energy, environment and sustainable' development - EURATOM**	**979**	**7%**
Key Actions: • Systems and services for the citizen • New methods of work and electronic commerce • Multimedia content and tools • Essential technologies and infrastructures	3120		Key Actions: • Controlled thermonuclear fusion • Nuclear fission	930	
Competitive and Sustainable Growth	**2705**	**18%**	**HORIZONTAL PROGRAMMES**		
Key Actions: • Innovative products, processes and organisation • Environmentally-sensitive mobility and intermodality • Land transport and marine technologies • New perspectives for aeronautics	2122		**International role of Community research** **Promoting innovation and the participation of SMEs** **Improving human research potential and the socio-economic knowledge base** Key Action: • Improving the socio-economic knowledge base	**475** **363** **1280**	**3%** **2%** **9%**
			JRC EC and EURATOM	**1020**	**7%**

Source: (78)

- **Organisation of production and work** – The aim is *"to move toward innovative high performance industrial systems, agile customer-driven networked industrial and related services enterprises."*

The EC has set out a range of research areas that addresses each of these objectives, for each phase of the product lifecycle (**Table B4.2**).

TABLE B4.2 FP5 INNOVATIVE PRODUCTS, PROCESSES AND ORGANISATION

	Phase of Product Life Cycle		
Objective	**Design and Pre-production**	**Physical Production**	**Operation and End-of-Life**
Efficient production	Integrated product-service design	Advanced production/construction technologies	Safe and reliable extended life of products and industrial systems
Intelligent production	Design of products and production systems	Intelligent manufacturing and processing	Monitoring and optimal use of industrial systems
Eco-efficient processes and design	Eco-efficient design of products and processes	Cleaner processes, products, and eco-efficient technologies	Product recovery and waste recycling
Organisation of production and work	New methods of organisation, work and human capital improvement	Adaptation of enterprises and human-oriented production	Knowledge, learning and management of change

Source: (79)

In addition, the generic activities for this thematic programme include 'materials and their technologies for production and transformation'. A budget of 410 million Euros has been set aside (15.2% of the budget for the thematic programme). This activity has four objectives:

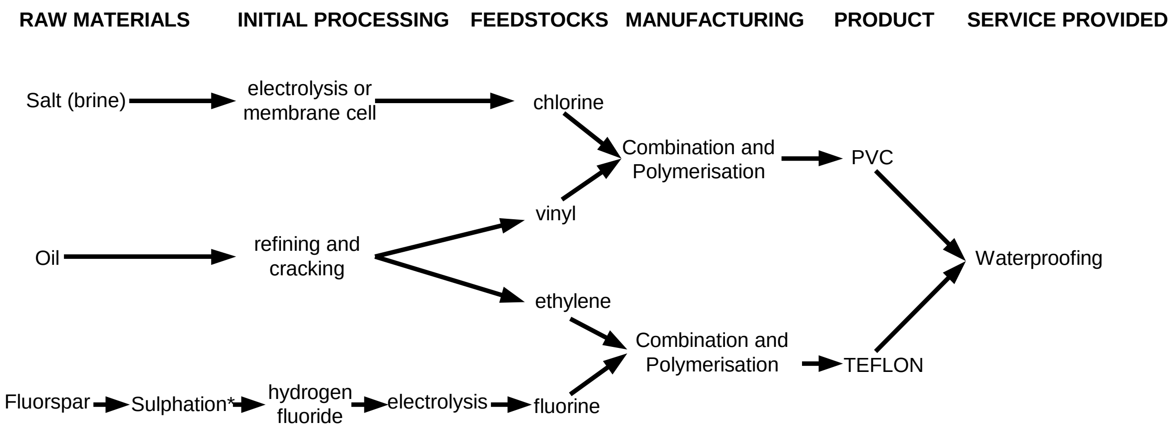
- **Cross-cutting generic materials technologies** – e.g. use of nanotechnology and molecular engineering. Research aimed at environmentally safe new production technologies for novel composites and other materials.
- **Advanced functional materials** – including environmental compatibility
- **'Sustainable' chemistry** – based on clean processing routes and efficient use of resources, including the use of renewable raw materials
- **Expanding the limits and durability of structural materials** – including ensuring that materials and their production processes are 'sustainable'.

ANNEX C CASE STUDY: WATERPROOFING THE MILLENNIUM DOME

Among the controversies surrounding the Millennium Dome on the Greenwich Peninsula in London, one which has special relevance for this report developed during the construction of the Dome, when it was revealed that the roof would be waterproofed with polyvinyl chloride (PVC). A number of environmental organisations complained about this, as it was their position that PVC presented unnecessary risks to health and the environment. The alternative of using Teflon (polytetrafluoroethylene) was suggested on the grounds that the risks were lower, and that it represented a more modern approach (compared to the 'old' industry represented by PVC).

A classic stand-off then ensued with each side of the debate claiming the 'environmental high-ground'. Without attempting to adjudicate on this, this case study illustrates the complexities involved in making such judgements, and the need to consider the full life cycle of the products involved. The Figure below shows only a bare skeleton of the life cycles.

FIGURE C1 THE MANUFACTURE OF PVC AND TEFLON



* sulphation is reaction with sulphuric acid

Source: POST

Each material used, each process adopted and each substance produced in both 'chains' has some potential to cause harm to the environment. For example, electrolysis of brine is most often carried out using equipment that uses mercury, although membrane cells are increasingly used. The extraction of fluorspar creates waste, and its conversion to hydrogen fluoride requires sulphuric acid (which needs to be neutralised with alkali which is a by-product of the chlorine manufacturing process). PVC manufacture involves the creation of vinyl chloride, which is a harmful substance. After the end of its useful life, PVC is often incinerated, and this can lead to the formation of dioxins (known carcinogens).

GLOSSARY

ACBE	Advisory Committee on Business and the Environment
ACCP	Applied Catalysis and Catalytic Processes
ACCPE	Advisory Committee on Consumer Products and the Environment
ACU	Alternative Crops Unit
AllChemE	Alliance for Chemical Sciences and Technologies in Europe
BAT	Best Available Techniques
BATNEEC	Best Available Techniques Not Entailing Excessive Cost
BBSRC	Biotechnology and Biological Sciences Research Council
BCSD	Business Council on Sustainable Development
BiE	Business in the Environment
BMB	Biotechnology Means Business
BPEO	Best Practicable Environmental Option
CASE	Collaborative Awards in Science and Engineering
CBI	Confederation of British Industry
CEFIC	European Chemical Industry Council
CEST	Centre for the Exploitation of Science and Technology
CIA	Chemical Industries Association
CT	Cleaner Technology
CTP	Clean Technology Programme
DETR	Department of the Environment, Transport and the Regions
DTI	Department of Trade and Industry
EA	Environment Agency
EEBPP	Energy Efficiency Best Practice Programme
EIC	Environmental Industries Commission
EIS	Enterprise Investment Scheme
EMAS	Environmental Management Accreditation Scheme
EMS	Environmental Management System
ENE	Energy and Natural Environment
EOP	End-of-Pipe
EPA 1990	Environmental Protection Act 1990
EPE	European Partners for the Environment
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
ETBPP	Environmental Technology Best Practice Programme
FGD	Flue Gas Desulphurisation
FP5	Fifth Framework Programme
FPF	Foresighting Facilitation Pack
FPIG	Foresight Process Industry Group
GCN	Green Chemistry Network
GEC	Global Environmental Change
HEI	Higher Education Institution
ICC	International Chamber of Commerce
IChemE	Institution of Chemical Engineers
IMI	Innovative Manufacturing Initiative
IPP	Integrated Product Policy
IPPC	Integrated Pollution Prevention and Control

ISO	International Standards Organisation
LAAPC	Local Authority Air Pollution Control
LCA	Life Cycle Analysis
MAFF	Ministry of Agriculture, Fisheries and Food
MPBP	Manufacturing, Production and Business Processes Panel
NRE	Natural Resources and Environment Panel
OECD	Organisation for Economic Cooperation and Development
OST	Office of Science and Technology
PTP	Postgraduate Training Programme
R&D	Research and Development
RAE	Royal Academy of Engineering
RCEP	Royal Commission on Environmental Pollution
RSC	Royal Society of Chemistry
RTD	Research, Technological Development and Demonstration
SEPA	Scottish Environmental Protection Agency
SFLGS	Small Firms Loan Guarantee Scheme
SMART	Small Firms Merit Award for Research and Technology
SME	Small and Medium-sized Enterprise
SPUR	Support for Products Under Research
STI	Sustainable Technologies Initiative
TCS	Teaching Company Scheme
TQM	Total Quality Management
UKEEI	United Kingdom Eco-Efficiency Initiative
WBCSD	World Business Council on Sustainable Development
WICE	World Industry Council for the Environment
WMR3	Waste Minimisation through Recycling, Reuse and Recovery

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