GLOBAL
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Innovation and the Environment:

Challenges & Policy Options for the UK

Final report from workshops sponsored by the Economic & Social Science Research Council's Global Environmental Change Programme

Imperial College Centre for Energy Policy and Technology & the Fabian Society

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- The analysis of the environmental impact of energy-related pollution on ecosystems and human health.
- The economic, legal and institutional aspects of energy and environmental policies.

The growth of the energy industry in the 20th century rested on far-reaching innovations and huge investments,with the creation of new disciplines in mining,petroleum,chemical,civil,electrical and mechanical engineering. All this required equally far-reaching investments in university education and research.The requirements of the 21st century will be no less demanding.The energy industry is going through a period of rapid liberalisation,globalisation and technological development. The world market grows by an amount equal to the entire UK market every year, yet 2 billion people are still without modern energy.At the same time, local, regional and global pollution will need to be reduced substantially.Technological advance could bring about large reductions in pollution per unit of energy produced and consumed.But this won't happen by itself - supportive policy frameworks and more efficient resource management practises must also be developed.

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The Fabian Society

The Fabian Society has played a central role for more than a century in the development of political thought and public policy on the left of centre. Analysing the key challenges facing the UK and the rest of the industrialised world in a changing society and global economy, the Society's programme aims to explore the political ideas and policy reforms which will define progressive politics in the new century.The Fabian Society is unique among think tanks in being a democratically-constituted membership organisation.It is affiliated to the Labour Party but editorially and organisationally independent. Through its pamphlets,discussion papers,seminars and conferences the Society provides an arena for open-minded public debate.

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Executive Summary

This report is the outcome of a series of Workshops on 'policy support for environmental innovation', held in summer and autumn of 2000 by the Imperial College Centre for Energy Policy and Technology, in collaboration with the Fabian Society, with support from the ESRC Global Environmental Change Programme. The workshops brought together[1]:

- Policymakers and senior government advisors;
- Representatives from industry, the investment community and specialist organisations;
- Former Fellows of the Global Environmental Change Programme and other academics active in this area.

The aims of the Workshops were to assess the role and potential of innovation in addressing environmental problems,to consider the role of current instruments of policy in promoting innovation, and to assess the merits of new policy options for the UK.

This report will give policymakers:

a Evidence on the importance of innovation in addressing environmental problems.
b The intellectual argument for specific support for environmentally oriented innovation.
c Analysis of policy options to support innovation,and evidence that such an innovation-focussed approach can work.
d Recommendations and 'next steps' for developing current policies.

The principal recommendations address:

1 The formulation of long-term strategies and goals for the development of technologies and practices for solving environmental problems.
2 The use of investment incentives,including tax allowances,to support technologies in their early phases of development.
3 Consolidation of existing funding mechanisms to finance innovative technologies,in partnership with industry and private sources of capital, for both large and small applications.
4 The instigation of prizes for meritorious innovations that solve especially difficult problems in a cost-effective way.
5 Use of public procurement policies for educational purposes and to encourage the development and use of innovative technologies.
6 Resuscitation of R&D programmes,particularly in energy, which have languished seriously since the 1980s.

[1] See Annex 1 for list of Workshop participants

Acknowledgements

Thanks are due to the UK Economic and Social Science Research Council and the former Global Environmental Change Programme for supporting the Workshops,and to the participants from industry, government departments and academia who contributed so openly to the discussions, which made the Workshops a success and a pleasure to hold.

1 Introduction

This report sets out the case for supporting technological and organisational innovation to tackle environmental problems,in a way that would be consistent with achieving economic growth and social progress.It analyses options for supporting such ‘environmental innovation’ and makes recommendations for developing current UK policies.

It is now widely argued that there is a need to accelerate trends to de-couple environmental damage from growth in GDP.This is frequently referred to as increasing resource or environmental productivity, i.e. raising the economic output per unit of resource use and reducing environmental damage per unit of output.In his recent speech to the CBI and Green Alliance, the Prime Minister referred to the possible need for a “tenfold increase in the efficiency with which we use resources by 2050”[2]. The Department of Trade and Industry has identified improving resource productivity as a key objective in its Sustainable Development Strategy[3].

The key to improving environmental productivity is innovation - the development of less damaging products,services and methods of production.Innovation here refers to all stages in the process by which new ideas become economic realities - from invention through research and development, demonstration,and the introduction and diffusion of new ideas in the market place (or indeed in the public sector),and covers both technological and organisational advances.

We are of course living in a highly innovative period,with rapid technological development occurring alongside profound changes relating to the liberalisation of markets and the globalisation of economic and cultural interactions.Innovative use of knowledge to create high value products and services will be central to competitive advantage and future prosperity in this new economy. However, it cannot be assumed that innovation per se will necessarily lead to environmental improvement.

UK Government policy, notably through its 1998 Competitiveness White Paper[4], recognises the importance of business and government working together to promote investment and technological innovation.At the same time, the Government is playing a leading role, both nationally and internationally, in promoting environmental protection and sustainable development[5]. However, it is striking how little these two areas have been ‘joined-up’:

- Innovation policies have placed little priority on the environment, whilst
- Environmental policies have focussed on near-term,near-commercial ‘solutions’,and have neglected the development of technologies and practices of considerable economic and environmental promise in the longer-term.

The report develops the case for supporting innovation directly, to augment the ‘standard’ instruments of environmental policy.

The objectives of such policies would be:

- To bring about appreciable reductions in environmental damage per unit of output;
- To create options for solving environmental problems and to reduce the economic costs of environmentally better practices;
- To ensure the UK is a world leader in the rapidly expanding markets for cleaner technologies.

The report is intended to give policymakers:

a Evidence on the importance of innovation in addressing environmental problems (Section 2).

b Analysis of and arguments for specific policy options to support environmental innovation (Section 3).

c Recommendations for practical policy developments (Section 4).

[2] Prime Minister, Speech to the CBI/Green Alliance Conference on the Environment, 24 October 2000.

[3] DTI (2000), Sustainable Development Strategy

[4] DTI (1998), Our Competitive Future:Building the Knowledge Driven Economy

[5] DETR (1999), A Better Quality of Life:UK Strategy for Sustainable Development

2 The Case for Innovation Policy

Over the last hundred years,when serious efforts have been made to address environmental problems,the challenge of doing so has been met.In many cases environmental damage per unit of output has been cut dramatically through new processes and products,and new ways of providing services and managing resources - that is,through innovation.

Innovation is not the only means by which environmental problems may be tackled,nor is it sufficient alone. Nevertheless it is clear that continued and accelerated innovation will be essential if consumption growth is not to outstrip our capacity to reduce local environmental impacts, particularly in the developing world,and to tackle pressing global problems,such as climate change and continued degradation of natural resources and ecosystems.There are compelling arguments that policy must target environmental innovation more specifically and effectively if this is to be achieved.This section therefore provides evidence of the importance of innovation,and outlines the case for more targeted policy support.

a The Importance of Innovation

The importance of technological and managerial improvement in improving environmental efficiency is becoming increasingly widely accepted.The reasons for this are best illustrated by examples. Table 1 compares environmental impacts per unit of output for a range of air and water pollutants (a) before and (b) after a ‘good’ practice is in place. Note the orders-of-magnitude reductions in pollution the changes in technologies and management practices bring about once they are fully adopted.Box 1 provides a further illustration based upon the example of vehicle exhaust emissions that contribute to local and regional pollution problems. Emissions declined markedly in the UK during the latter decades of the 20th century once new technologies and practices were introduced.Box 2 provides another example for the case of the reduction of pollution in the Mersey Estuary.

The scope for innovation is far from exhausted. For example, emerging clean technologies for electricity generation,building energy service provision and vehicle propulsion include:

- renewable energy technologies,in particular:
  - multi-megawatt wind machines for offshore application;
  - ‘third generation’ advanced photovoltaics based upon semi-conducting polymers and dye sensitised glass;
  - ocean stream and wave energy devices;
  - advanced biomass combustion technologies and fuels
- advanced energy storage systems to store low emission energy (e.g.from renewables and base load electricity generation plant).
- fuel cells,using hydrogen or other fuels, for decentralised electricity generation and vehicle propulsion
- combined heat and power using micro-turbines
- high fuel efficiency hybrid (petrol- or diesel-electric) vehicles
- improvements in the design of buildings, vehicles and processes such that energy efficiency is greatly improved compared to conventional systems.

Historically many kinds of air and water pollution have been reduced by orders of magnitude through changes in technologies and management practices; there is no evidence that the scope for innovation is exhausted in relation to current and emerging problems.

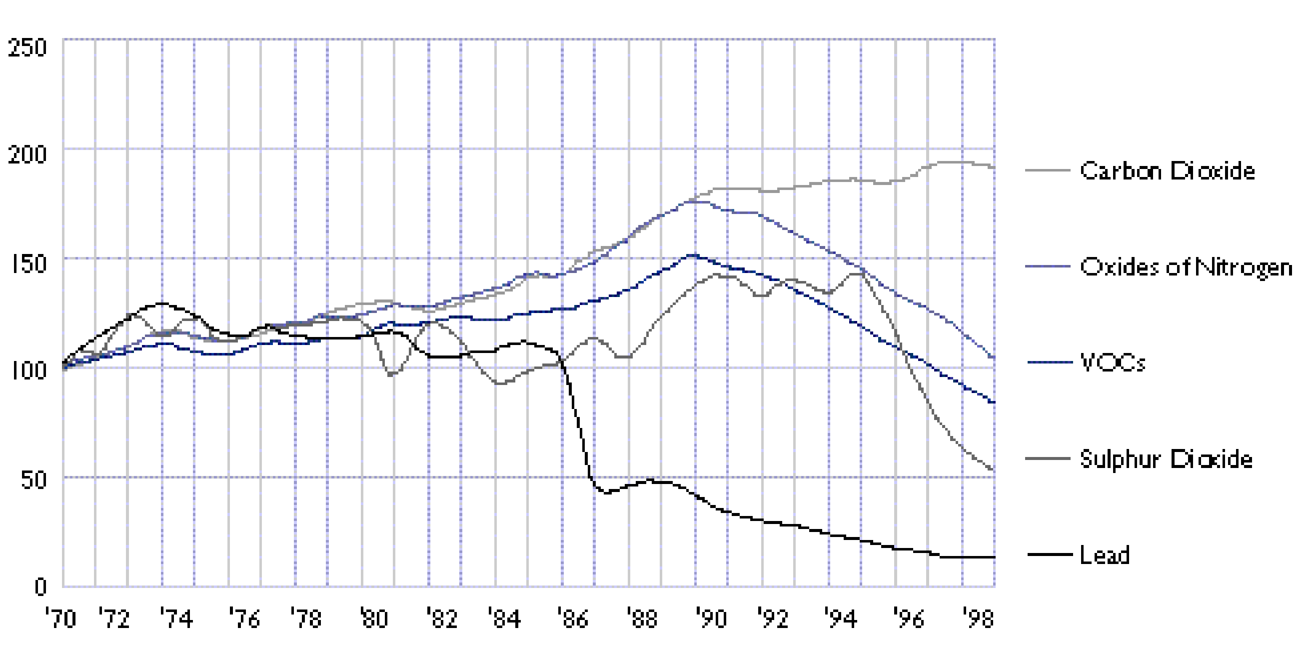
Table 1 Pollution Intensities and Costs of Technologies for the Prevention and Control of Air and Water Pollution, Relative to Those of the Polluting Technologies They Displace.

Source and Type of Emissions or Effluents.	Index of Pollution Per Unit Output (polluting practice = 100) Polluting	Low-Polluting	Indic-ator of Added Costs, %	Comments on Nature of Low-Polluting Practice (see also the table's footnotes)
Electricity Generation:				
PM only	100	< 0.1	< 0 to 2.0	Natural gas;'clean coal' technologies;low-sulphur
PM and SO_2	100	0 to 10 a/	< 0 to 8 a/	fuels;low-NOx boilers and emission control
PM,SO_2 and NO_x	100	10 to 30 a/	<0 to 10 a/	catalysts.
Motor Vehicle Emissions:				
Lead	100	0	≈3.5%	Unleaded, reformulated fuels and catalytic converters
Volatiles (VOCs)	100	4		(petrol engines). Low-sulphur fuels and particulate traps
Carbon Monoxide	100	4		(diesel).The 3.5% figure is relative to total discounted
Nitrogen Oxides	100	20		vehicle and fuel costs and is roughly the same for diesel
SO_2 (diesels)	100	5		and petrol engines.
PM (diesels)	100	<10		
Household Fuels in Developing Countries:				
Smoke from firewood and dung	100	0	< 0	Gas,LPG and Kerosene. Stoves with flues
		<1 to 5		
Soil erosion (sediment yield)	100	<0 to 1	< 0	Agro-forestry and erosion-prevention practices
Renewable Energy Technologies for Reducing CO2 Emissions:				
Wind (electric power)	100	0	0 to 30	Costs declined 5-fold since 1985
Biomass (electric power)	100	< 0	0 to 100	Costs vary with source of fuel
Biomass (ethanol)	100	0	≈50	Brazilian data.Costs declined by factor of 3 since 1980s
Photovoltaics (off-grid)	100	0	≤0	High insolation areas.Relative costs vary greatly with
Photovoltaics (grid)	100	0	0 to >400	application.Costs have declined 50 fold in 25 years.
Solar-Thermal (electricity)	100	0	≈50-100	High insolation areas only.
Geothermal (electricity)	100	0	≤0	Costs highly location specific
Fuel Cells (electricity and vehicles)	100	0	Not available	Emission assume renewable energy source for hydrogen.
Industrial and Municipal Wastewater Treatment (primary, secondary and tertiary treatment):				
Primary and Secondary:				
• BOD	100	5	1-2 %	Based on costs of $1.9 per m^3 and typical volumes of
• SS	100	5	of value	wastewater per unit value added in municipal areas.
• TP	100	5	added in	
• TN	100	65	cities	
As above plus Tertiary:				Ditto, at costs of $2.5 per m^3.
• BOD	100	3	1.5 -3 % of	
• SS	100	5	value added	
• TP	100	5	in cities	
• TN	100	13		

Sources and notes:See Annex 2.

a/ The index of pollution here refers to SO2 only, since the figure for PM is provided in the preceding row. Similar remarks apply to NOx in the following row. The estimates of added costs are for PM in the first row, PM and SO2 in the second row and for all three pollutants in the third row.

Box 1 Changes in vehicle tailpipe emissions for the UK since 1970



Index of Trends in UK Vehicle Emissions from Road Transport:
Base Year 1970 = 100
(derived from UK DETR air quality statistics database)

The index is derived from data for annual emissions from all road transport over the period shown.Changes to emissions reflect the substitution and gradual dissemination (as the vehicle stock is replaced) of cleaner technologies and fuels.With the partial exception of lower sulphur fuels,all changes have been driven by regulatory and fiscal pressure (and often more stringent, earlier legislation overseas). All pollutants show a marked response to policy and associated technological changes,with a tendency towards rising emissions (as vehicle numbers grow) reversed in all cases except CO_2. In most cases a continued downward trend reflects gradual replacement of older vehicles with their less polluting successors as the vehicle fleet turns over:

- The dramatic reduction in lead emissions follows the introduction of lead-free petrol in 1986 combined with fiscal incentives for the use of lead-free, encouraging vehicle 'conversion' where possible, mandatory lead-free running for all new vehicles shortly afterwards,and continued reductions in the lead content of leaded grades.Lead was removed from all fuel grades last year and emissions from road transport are now close to zero.

- Emissions of volatile organics (VOCs) and of oxides of nitrogen show a marked reversal of their upward trend following the introduction of catalytic converters on all new cars in 1990 and,to a lesser extent (for VOCs),tighter standards for evaporative emissions.

- The marked reduction of sulphurous emissions follows the widespread introduction of low sulphur diesel in the late 1990s,this trend is expected to continue as sulphur levels in all fuels are reduced further.

- It is possible that CO_2 will follow a similar pattern in response to the EU-wide voluntary agreement with motor manufacturers to reduce CO_2 emissions.

Similar patterns have been found in other sectors, following the introduction of environmental regulation and technology development.SO_2 emissions from power generation have declined at 7 percent per year since 1980. For domestic and industrial smoke the rate of decline was around 13 percent per year in the period 1953 (the beginning of the end of the 'great smogs') to 1973. It is the changes in technologies and practices for the prevention and control of pollution,brought about by environmental policies,that has the decisive effect on pollution abatement.

Sources:E.Ashby and M. Anderson,1981,Figure 3 p. 188 The Politics of Clean Air, Oxford OUP, and UK Air Quality Statistics Database, maintained by AEA Technology for the DETR http://www.aeat.co.uk/netcen/airqual/statbase/dbasehome.html

Box 2
Pollution Reduction in the Mersey Estuary Since the 1970s

A report on the Mersey Estuary by the former National Rivers Authority (1995) shows the importance of technical progress in wastewater treatment for reducing pollution.Data are shown in the following table;the footnotes provide technical comments (note the variety of industries and technologies involved).

Pollutant	Initial	Recent	Percent Reduction	Years to which 'Initial' and 'Recent' data refer
BOD - from sewage, t/day	240	15[a/]	94	1972 and 2000 (projected)
- total,t/day	340	50	85	ditto
Mercury[b/], t/year	57	< 0.5	> 97	1975 and 1993
Cadmium discharges,t/year[c/]	0.28	< 0.05	82	1985 and 1991
PCP yearly mean concentration, µg/l[d/]	4.3	0.2	95	1988 and 1992

Source:National Rivers Authority, 1995.

[a] From treated sewage. All sewage is now treated,the BOD from untreated sewage being nearly 200 t/day in 1972.

[b] Mostly from chlor-alkali plants,which produce chlorine from the electrolysis of brine. The report comments that "Since the early 1970s,when scientific attention was focussed on the impact of mercury on the environment,there has been substantial investment by industry to reduce the amount of mercury discharged (which) has brought about a dramatic reduction over the past 15 years." One firm (ICI) invested £25 million in improved effluent treatment process, another introduced a "membrane cell chlorine plant,which is a mercury free process."
The report adds that concentrations in the Estuary have only declined by half so far because there remains an accumulated reservoir of mercury in the Estuary arising from older sediments laid down in earlier times.

[c] The report notes:"In 1985 there were 10 industrial concerns,mainly electroplaters,discharging cadmium to the Estuary via untreated sewers."

[d] The data shown are at a point known as Canal Bridge. The report comments:"A major source of pentachorophenol (PCP) in the North West is textile finishing where PCP has traditionally been used as a rot-proofing agent after the bleaching and dyeing process".In 1988,when and EC directive controlling PCP came into force, it became apparent that a number of watercourses downstream of the treatment works receiving textile finishing wastes, were failing to meet the required environmental quality standard. Discussions with industry led to changes in working practices at sites to minimise losses of PCP; improved flow balancing; off-site disposal of spent liquors; and in some cases cessation of use."

This report quotes the findings of a government field survey in 1869,and provides a sobering reminder of how long it may take policies to be acted upon:

> "When taking samples... we saw the whole water of the River Irwell,there 46 yards wide, caked over with thick scum of dirty froth,looking like a crusted surface. Through this scum...heavy bursts of bubbles were continually breaking, evidently rising from the bottom...the whole river was fermenting and generating gas. The air was filled with the stench of this gaseous emanation... The temperature of the water was 76° F and that of the air 54° F." Despite a series of Acts in 1876 (requiring sewage discharges to be "rendered inoffensive"),1951-1961 (Pollution Prevention Act),1960 (Clean Rivers Act),1973 (Water Act),and 1974 (The Control of Pollution Act),in 1983 the Secretary of State for the Environment declared " ...today, the river is an affront to the standards a civilised society should demand of its environment. Untreated sewage, pollutants and noxious discharges all contribute to water conditions and environmental standards that are perhaps the single most deplorable feature of this critical part of England."

A further series of Acts followed,stimulated by the UK's entry to the EU and the Mersey Basin Campaign. An extensive programme of investments in primary, secondary and tertiary treatment, plus regulations requiring companies in the region to reduce and pre-treat their water wastes,has since led to the improvements summarised in the above table.As can be seen,the influx of pollutants was reduced considerably.The report concludes that the "tide of pollution has turned... If there is a cloud it is the reservoir of contamination in the sediments which could be slow to disperse."

b The Need for Innovation Policy

The contribution of innovation is therefore considerable and past policies have been effective in driving this. Nevertheless there are important reasons for considering policies which go beyond conventional approaches and target innovation more directly.

(i) The problem of time lags

Historical analysis shows that there have been very considerable time lags in achieving major improvements after a policy has first been announced - typically of a quarter or half a century, and sometimes longer. This is partly because policies themselves are often gradualist, being constrained by the technologies available at the time; we can see this now with current policies toward global warming. Secondly, the technologies themselves take time to develop, e.g. 25 years in the case of flue gas desulphurisation[6]. Thirdly, even when developed, and except where retrofitting is feasible and inexpensive, the rate at which they can be substituted is limited by the turnover rate of old, polluting capital stock - typically ranging between 10 and 30 years, or longer. Fourthly, technology infrastructures, such as for transport systems and fuel supply, may shape the range and potential of individual technology options for decades.

[6] Balzheiser and Yeager (1987)

For all these reasons the path of a policy is as important as its end point, with innovation policies being especially important in the early phases. The problems posed by time lags are frequently overlooked during traditional analysis, which is concerned with the long-run efficiency of environmental improvement and the costs of alternative policies. The evidence is clear that environmental regulations and taxes have given rise to major innovations in pollution prevention and control. But given the scale and seriousness of current environmental problems, the historic timescales for such innovation are no longer available. The process of innovation needs to be speeded up. It is for this reason that there now needs to be consideration of additional policy instruments to stimulate innovation directly. The aim of such instruments is to bring forward options for reducing pollution and lowering costs faster than would otherwise occur.

The path of a policy is as important as its end point, with innovation policies being especially important in the early phases.

(ii) Markets and economic benefits

Effective policy support for environmental innovation is also important if the economic benefits that accrue from the development of environmentally beneficial goods and services are to be secured. The size of the 'environmental industry' is very large. Value added in environmental goods and services in world markets runs into hundreds of billions of dollars, is rising rapidly, and is projected to continue to do so (see Table 2).

Table 2 Estimates of the Global Environmental Goods and Services Industry ($US bn)

	1992	2000	2010
North America	100	147	240
Latin America	2	5	15
Europe	65	98	167
Asia Pacific	85	63	149
Total	210	320	570

Source: OECD (2000).

But a focus on a fairly narrow set of environmental technologies that 'bolt on' to existing products and processes seriously understates the importance of environmental innovation. More difficult to quantify, but certainly larger still, is the potential for inherently cleaner products and processes. What is beyond dispute is that this is a profitable area of activity. In the first half of last year, the return on equity of the Dow Jones Sustainability Group Index averaged 15%, compared with just 8% for companies in the regular Dow Jones Index. And the potential markets are huge: for example, over 5 million MW of new electricity generating capacity will be needed world-wide in the first half of this century, plus another 3 million MW to replace the capacity in operation today, all of which will need to meet increasingly stringent environmental regulations, including those relating to the reduction of carbon emissions.

Thus, there are appreciable opportunities for exports and foreign investment, and as environmental policies around the world spread and tighten, investment and employment opportunities in low polluting technologies and practices are likely to grow for many decades. However, the historical evidence suggests that countries that do not provide a supportive framework for environmental innovators may lose place very rapidly as new markets develop, and become importers of the technologies that environmental policies demand, an example being the UK's loss of place in wind turbine manufacturing.

(iii) The 'win-win' argument

The size of the potential market for cleaner products and for innovation to drive both environmental improvement and reduced costs is summarised by the 'win-win' argument:

Environmental innovation = environmental improvement + greater profitability + jobs and exports

This has given rise to the suggestion by some commentators that a laissez faire attitude to the development of environmentally friendly technologies and practices is justified. The most immediate objection to this is that the 'win-win' argument is true only in a few heavily publicised but atypical cases. In fact, as we explore below, win-wins do occur but the impact of environmental innovation upon cost is often highly uncertain at the outset, before investment in new methods begins.

However, the problem with the argument is not whether it is widely applicable or not. First, it is unnecessary to appeal to 'win-win' to justify the economic merits of a policy; the case for policy rests on its environmental benefits (the reduction of external costs) in relation to the costs of the policy. Second, it obscures a process that tells us far more about the role of environmental policies and their economic and environmental effects over time. This is that:

1 A policy, or the expectation of one raises the private costs of polluting practices.
2 This encourages a search for ways of reducing pollution. Simultaneously, there will also be an effort to reduce the costs of compliance with the policies. In the large majority of cases, the search is successful, and opportunities for reducing pollution are identified. Some are win-win, others are not.
3 Substitution towards the lower polluting practices begins. This requires investment and a redeployment of labour to produce and operate and maintain the new practices. The share of value added begins to rise in the low-polluting practices, to fall in the polluting practices, and the former (depending on the impetus provided by policy) gives rise to a new growth industry.

Far from justifying a laissez faire approach to environmental innovation therefore, the 'win-win' scenario reinforces the point that the impact of policy on the path of innovation and upon the timescale involved are of paramount importance.

(iv) The cost of innovation

One of the most commonly cited barriers to innovation is cost. New technologies and products require investment. For individual companies considering environmental innovations this is a key issue (see Box 3). When considered in their early phases many innovations look expensive. However, when we look back historically at the costs of developing and introducing new environmentally improved technologies and practices, four features stand out:

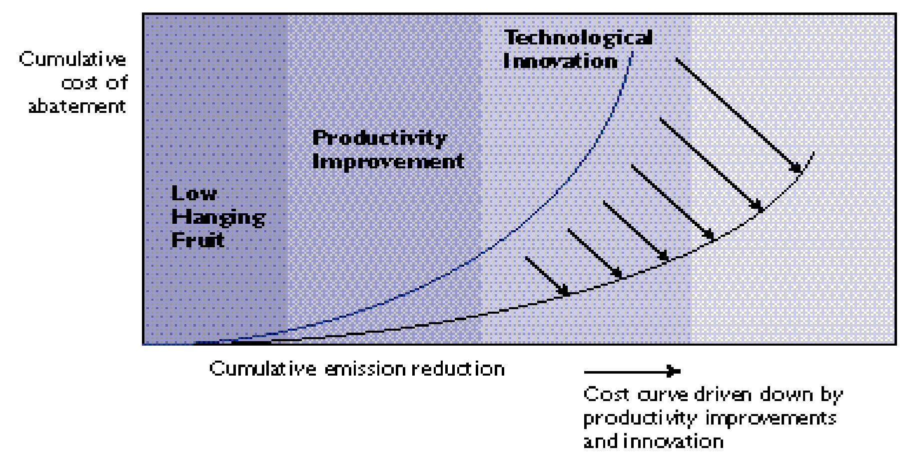
- First, though often appreciable in absolute terms, when expressed relative to the level of output or overall costs in an industry or activity, the costs of environmental control are generally small (again see Box 3).
- Second, in important cases costs have proved to be negative. The new low-polluting technologies and practices have been economically superior to the polluting options they displaced, even without consideration of their environmental benefits.
- Third, in many cases the search for environmental improvement has lead to a reduction in waste, efficiency gains and cost reductions. In other cases the added costs have been offset by efficiency improvements elsewhere in the industry. A good example is electricity generation: improvements in the efficiency of thermal fired power stations rose from roughly 30-35% in the 1950s to the 45% for coal-fired plant and 55% for combined cycle gas turbines today, far outweighing any cost increases arising from environmental controls.
- Finally, costs fall over time through 'learning-by-doing'. Box 4 gives examples of cost or 'learning' curves for several renewable energy technologies. We still do not know reliably what the future costs of the technologies will be. However research indicates that although widespread use might entail a significant increase in the costs of energy, an 'economic surprise' in which costs fall through innovation and market application is no less likely.

This leads to an important policy conclusion. Most analysis of environmental decision-making assumes that future costs of technological and other improvements are known. This assumption is often used for the private decision-making procedure of discounted net present value (NPV), and for its public counterpart cost benefit analysis (CBA). But the cost of future products and production processes - those developed through innovation - cannot be known, by definition. There is not a single cost,but probabilities attaching to an often wide range of possible future costs. Whilst it remains entirely appropriate to continue to use CBA and NPV in most instances, it is possible for environmental policymaking to take the dynamic of technological innovation into account - by explicitly focusing some policy measures upon innovation. We now turn to some of the economic arguments that flow from and underpin both this point and the observations above.

Box 3

Innovation, Efficiency and Costs: an industry perspective

Source:Courtesy of BP.



The figure shows a typical relationship between the cumulative cost and cumulative improvement in environmental performance. The curve is relatively shallow initially indicating that initial gains can be achieved at relatively low net cost. Projects in this region of the curve are often referred to as ‘low hanging fruit’ and can be carried out immediately with conventional approaches. Beyond this further gains are achieved at progressively higher costs and the gradient of the cost curve steadily increases. Projects in this region are generally not cost effective using conventional approaches and some development is required to drive down the cost curve to one that is more economically tractable. This region is termed ‘productivity improvement’ and successful projects depend on improvements in the core technology or its implementation. Projects in both in these regions are the immediate focus the company’s technological resources. In the final region, the cost curve increases rapidly and further improvement is only obtained using approaches at a prohibitive cost. New technological approaches must be found to improve environmental performance further. This is the region of ‘technological innovation’.

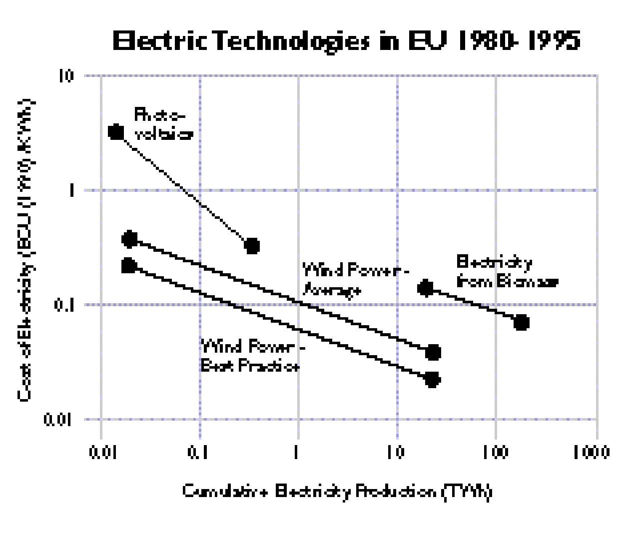
Box 4

Cost curves and the Positive Externalities of Innovation: the example of Renewable Energy

Source:International Energy Agency (2000),

Experience Curves for Energy Technology Policy

The curves show the costs of photovoltaics, wind turbines and electricity from biomass declining with investment and operating experience-’learning-by-doing’. Costs are often correlated with the cumulative volume of production to estimate the effect. Similar curves have been projected for fuel cells, which currently have costs in the range $2,000-5,000 depending on type and application, but are variously projected to fall to between one-fiftieth and one-twentieth of these levels once production on a significant scale begins. The IEA estimates that the percentage reductions in costs for each doubling of the cumulative volume of production is 18% for wind, 20-35% for photovoltaics, and 15% for electricity from biomass. The effect has been noted in for many technologies and industries historically, but it is particularly strong in the early phases of a technology’s development, when experience is accumulating rapidly, and the volume of production doubles many times over from an initially small base. Hence support for a technology can be critically important in its early phases.



The declines in costs arising from investment in one period give rise to positive externalities, in the form of lower costs, and sometimes through the exploitation of discoveries that would not otherwise have been made, in later periods. The value of such externalities is the present value of the product of the cost reductions arising from investment in the period in question times the expected volumes of future use. The cost reductions arising from an investment in any particular period may often be small (they are linked to the slope of the learning curve), but if the volume of prospective use is large, the external benefits can be appreciable, amounting to 40-60 percent of capital costs or more, depending on market growth.

c The Principles of Environmental Innovation Policy

The stimuli provided by environmental policies,or the expectation of them,have been central in driving innovation and associated markets for cleaner technologies.Nevertheless,given the time-lags involved,the central importance of innovation in tackling environmental problems,and the scale of current problems,are the 'standard' instruments the 'best we can do'?

The question can be answered by reference to the orthodox economic case for environmental policy, which fails to understand the role of innovation in environmental improvement.It rests on the assumptions that the marginal cost and benefit curves are well-known and well-defined and that the 'end-point' of policy can be clearly identified.In practice however:

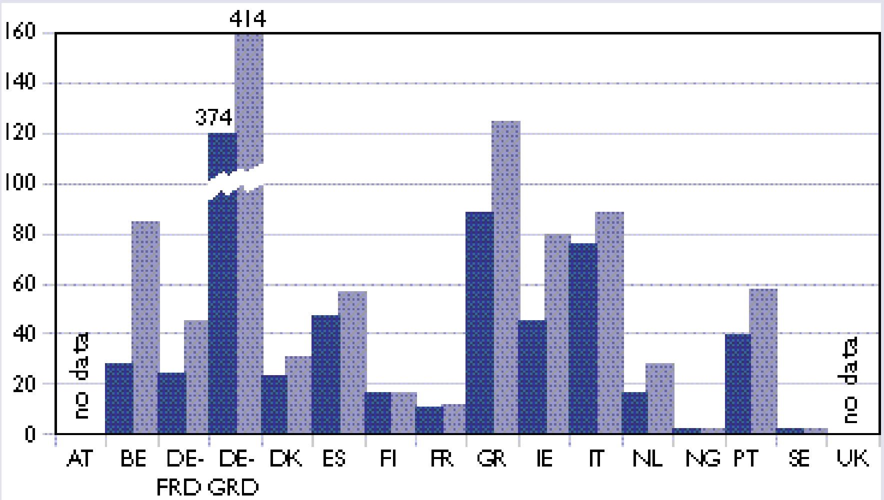
[7] Stirling (1998)

a The marginal benefit curves are not well-known or well-defined. These curves are very difficult to estimate, and the uncertainties are appreciable for most forms of pollution.Box 5 shows the range of uncertainties in external costs of electricity supply industry. Even the probability distribution of the costs of pollution,or the benefits of abating it,is frequently not known reliably. It is largely the magnitude of the uncertainties and risks that historically led much of environmental policy to be based on laws informed by scientific analysis rather than economic analysis.More recently, it has led the policy-making community, supported by academic research to develop more participatory approaches to policy making.[7]

b The marginal costs curves for pollution abatement are similarly not well-known or well-defined. Box 6 shows estimates of the range of costs of responding to climate change, which depend greatly on uncertainties in the costs of technologies.In practice, the lead times to develop low polluting options are long,rarely less than 15-20 years,and sometimes much longer. Also their costs are often uncertain, and cannot be estimated without R&D and demonstration projects, i.e. without investment to identify and explore options.Unleaded fuels and alternatives for CFCs are examples where the lead times were short and alternatives quickly emerged,but this is not the general rule.

c The end-point of a policy is highly uncertain. The time between a policy pronouncement and the time a final optimum equilibrium is reached,if it is ever reached at all,is usually a generation (PM,tailpipe emissions from vehicles),two generations (acid deposition), and may even extend to a century (municipal wastewater treatment and,perhaps,climate change).The path of a policy is often as or more relevant than its end point.

None of this undermines the general insight from economic analysis that pollution imposes external costs,and is a source of market failure that needs to be rectified by a tax,market-based instrument or a regulation. However, the analysis still focusses on end points rather than paths. Given the uncertainties underlying the costs and benefits of abatement,and the time lags involved developing new technologies and incorporating them into every day economic activities,there are appreciable benefits from policies that create options and enable environmental problems to be solved sooner rather than later.



Box 5
Uncertainties in the Estimates of External Costs

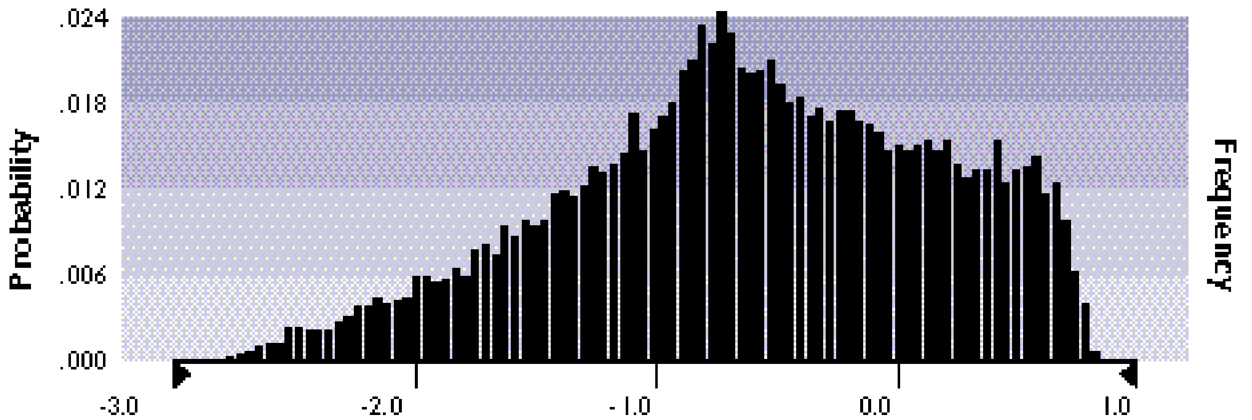
Estimates of the external costs of electricity supply industry in 15 European countries:Results from the EU 'ExternE' Project (1998),showing low and high estimates of average costs in mECU per kWh.

The range of uncertainties in estimates of external costs,despite many years of effort by economists,is wide even for local and regional air pollution from electricity generation.The above chart is based on the results of the EU "ExternE" project.The above estimates,which understate the actual range of possibilities,are the average not the marginal costs per kWh - curves for the latter are not available. Differences vary appreciably across countries with the levels of population exposed,and the siting and 'mix' of generating plant;France is estimated to have lower external costs because nuclear power accounts for most of the supply, and the external costs of nuclear wastes are ignored.Aside from some factors being neglected because they were too difficult to quantify, further difficulties arise in estimating the health and several other effects of pollution: e.g.of distinguishing between the damage arising from the source in question from that due to other sources,and more controversially of putting an economic cost on damages to people's health.(Rabl,2000).In the case of global warming,the estimates of external costs are much wider, ranging from less than five to several hundred dollars per ton of carbon emitted (Tol,1999).

Box 6 Uncertainties in the Costs of Abatement

Uncertainties on the cost-of-abatement side are also often large, and sometimes conceal the possibility of costs being lower than expected.Again,consider the costs of stabilising CO2 emissions over the long term.Most studies put these in the range of 0.5 to 4% of Gross World Product.However, few studies have made allowance for the possibilities of costs being reduced through innovation (Grubb, et.al,1996 and 2000).If we use elementary 'learning-by-doing' cost functions in the simulation models used to estimate costs, the conclusion emerges that an economic surprise cannot be ruled out.The following are the results of a simulation study at Imperial College, based on a range of values for the learning-curve parameter:

A Frequency Distribution of the Present Value of the Projected Costs of Gradually Substituting Renewable Energy for Fossil Fuels Over the Present Century.



Renewable Energy - Fossil Fuel Scenarios:Costs as % Gross World Product

Source: Papathanasiou and Anderson (2000)

The recommendation of this report is that an ideal policy is one that uses the standard instruments of regulation or market-based incentives to internalise external costs and,in addition,supports innovation directly.The case is three-fold:

1) The positive externalities of innovation.

All inventions and innovations that take root,whether environmentally related or otherwise, reduce costs or raise productivity or create possibilities that did not previously exist.In doing so, they also provide opportunities and sources of productivity gain to future generations,and so have a positive externality. [8] In these respects,environmental innovations are no different to other innovations.The differentiating feature of environmental innovation is that, by creating options and reducing costs,it also enables environmental problems to be solved sooner, and thus increases the environmental benefits.[9]

2) Uncertainty and risk,and the need to explore options.

As discussed earlier, the uncertainties and risks associated with environmental policies are large, and there is a value to policies that create or bring forward options that would not exist. Technically this is called the option value of a policy, which can only be realised through investment and operating experience.

3) The high costs of abatement and inelasticities of demand and supply response in the absence of alternatives.

In many instances short-term abatement costs can be extremely high.Carbon taxes, for example, would have to rise to politically unacceptable and possibly economically damaging levels before having a significant impact on carbon emissions.This is because near term energy demands and supply responses are inelastic. This means that in the short term,environmental taxes raise revenues,and may raise hackles,but have limited impact on environmental problems. In the longer term,products and infrastructures do change in response to price (and policy) signals.Accelerating the development of environmentally improved technologies will enable substitution to take place earlier, and at lower cost.

Direct support for environmental innovation thus complements the standard instruments of environmental policy: by giving rise to positive externalities, by reducing uncertainties and creating options,and so by lowering the long-term costs for substituting less environmentally damaging alternatives.

[8] See the famous paper by Arrow (1962) on the economics of learning by doing,and a recent paper by Baumol (1995)

[9] There is also the question whether the patent system is functioning as efficiently with respect to environmental innovations as it is for others; so far as we know, this has not been researched.

3 Options for Policy

Current Policies

The importance of business and government working together to promote investment and technological innovation was recognised in the 1998 Competitiveness White Paper[10], which defined the Government's role to be to:

- invest in capabilities to promote enterprise and stimulate innovation;
- catalyse collaboration to help business win competitive advantage;
- promote competition by opening and modernising markets.

The role of innovation in stimulating environmental improvement was not however given priority. Similarly, the Science and Innovation White Paper[11] provided generous support for research in key new areas 'that will shape life in the 21st century:genomics,e-science and basic technology such as nanotechnology, quantum computing and bio-engineering',whilst ignoring the potential and importance of environmental technology.

At the same time though,the Government has been playing a leading role both nationally and internationally in promoting environmental protection and sustainable development[12]. In particular, the UK programme on Climate Change[13] sets out the measures to meet the UK's target under the Kyoto Protocol of a 12.5% reduction in greenhouse gas emissions from 1990 levels by the period 2008-2012.One of the main instruments is the Climate Change Levy (CCL) on the business use of energy, with exemptions for electricity generated from renewable sources and good quality combined heat and power (CHP) generation.In the first year, £150 million of the money raised will be recycled,to accelerate the development and take-up of low carbon technologies and energy efficiency practices.Of this,£100 million will be allocated for a 100% first year Enhanced Capital Allowances (ECA) scheme for firms making approved energy saving investments,together with a further £33m to finance other business energy efficiency measures - these programmes being run by a new independent,non-profit making Carbon Trust.In addition,£17 million of CCL proceeds, together with similar amounts of lottery proceeds from the New Opportunities Fund,will be directed towards promoting the development of longer term renewable energy technologies, initially for offshore wind and energy crop installations.

The latter schemes represent a welcome step forward in using some of the revenue from an environmental tax to support innovation to tackle an environmental problem,in this case climate change.This section outlines a range of options for building on current policies in order to support a wide range of environmental innovation.

10 DTI (1998),Our Competitive Future:Building the Knowledge Driven Economy

11 DTI (2000),Excellence and Opportunity:A Science and Innovation Policy for the 21st Century

12 DETR (1999),A Better Quality of Life:UK Strategy for Sustainable Development

13 DETR (2000),Climate Change: The UK Programme

Future Policies: A Mix of Instruments

In recent years UK environmental policies have tended to focus on near-commercial technologies most readily applicable in the near-term. While such support is a necessary aspect of innovation policy, it has three limitations:

- In the absence of other measures,users import technologies and equipment from countries that provide incentives for R&D and innovation in the earlier phases of the technology development cycle-as infamously happened with wind turbine technologies under the NFFO.
- Technologies of much promise in the long-term,but which are still high on the learning (cost) curve, are neglected.
- The complexity of the innovation process and the network of actors and agents involved is glossed over.

The Workshops discussed the application of several instruments that would address these problems.Their advantages and disadvantages are summarised in the next section.They are not mutually exclusive and none purports to provide 'the answer' itself.Finding the best policy 'mix' is the key. Different instruments are better suited to different aspects of the innovation process:

- R&D in the earlier phases;strategic market niches (for example through public procurement) to support development in the 'pre-market' phases;and a mix of financial incentives to support further innovation and 'learning-by-doing' once technologies have been demonstrated and are closer to commercial viability.
- The next stage is 'near-commercial' development and diffusion of the technologies and practices, under the incentives provided by the standard instruments of environmental policy.

Problems also often differ greatly between industries and sectors,and between small and large firms within sectors,and this too has a bearing on the choice of instruments.The challenge is to create a suitable mix of policies that is robust across sectors and sizes of companies,and that facilitates a wide range of innovative activity.

There are three types of instruments available:targets;financial support, including mechanisms for raising finance;and political and corporate leadership.

a Long-range targets and obligations

Outcome-based targets,deliberately set beyond current best practices,based on assessments of what innovations can realistically deliver, and backed by promise of legislative or economic enforcement,are already becoming part of the UK policy framework.One example is the Renewables Obligation on electricity suppliers to generate 10% of their electricity from renewable sources by 2010,subject to the cost to consumers being acceptable.Voluntary agreements,such as that between the EU and the major car manufacturers to reduce CO_2 emissions,provide an alternative, more co-operative, mechanism.So long as the targets are credible and not merely aspirational,the advantage of this approach is that innovation is effectively 'designed-in' to the instrument. The Californian Zero Emissions Vehicle Mandate is an example - though this also illustrates some of the difficulties with target setting (see Box 7).Companies have the incentive to innovate and,depending on the time frame of the targets,a degree of choice over the technologies and practices needed to meet the target.Finally, by providing a clear signal of the direction of environmental policy, they influence company expectations and technology development, research, investment and marketing policies over the long term.

Economic analysis has drawn attention to a danger of target setting - but mainly to the setting of near-term as opposed to long-term targets advocated here. The former introduce rigidities,and in doing so may raise costs and drive technology development down the wrong path[14]. If the time horizon for a target is too near-term,companies must of necessity concentrate on near-term options to the exclusion of the development of promising long-term opportunities.Examples include extending the life of nuclear stations rather than, for example, developing off-shore wind or fuel-cells for combined heat and power.

Provided they allow for flexibility in the near term,long-term targets are an important instrument for influencing expectations and the directions of corporate and public policy.They do not, however, address the problem of financial risk.

[14] See Manne and Richels (1996) and Grubb et al.(1995) for differing views on this issue

Box 7

California Zero Emission Vehicle (ZEV) mandate

Encouraged by advances in battery electric vehicle technology, the California Air Resources Board (CARB) in 1990 acted to stimulate development of zero emission vehicles (ZEVs):cars,trucks and buses that produce no tailpipe or evaporative emissions.The Board adopted a requirement that 10% of the new cars offered for sale in California in 2003 (and beyond) would have to be ZEVs.In February 2000,the Board adopted a similar regulation for transit buses, requiring certain transit agencies to demonstrate zero-emission buses (ZEBs) in 2003 and to begin purchasing 15% ZEBs for their fleets in 2008. The proponents of this form of policy instrument argue that the benefits of the ZEV automobile regulation are now apparent:

a as a result of technological innovation, key components of electric vehicle technology have improved dramatically in terms of performance, cost,size and weight;
b the torque density of EV motors have increased nearly 8-fold and the power density of motor controllers has increased 5-fold;
c the major automakers have already put more than 2000 battery-powered ZEVs onto California's roads;
d significant advances have also been made in the design of ultra light body structures with very low aerodynamic drag coefficients;
e the regulation has spurred further technological advances in conventional IC power trains and other propulsion systems,to create a generation of super-clean vehicles known as super ultra low emission vehicles or "SULEVS" (generally fueled by gasoline or compressed natural gas),many of which are at a near commercial stage. For example:

- a number of conventionally powered vehicles are now certified to SULEV standard;
- fuel-efficient hybrids vehicles are emerging,powered by a combination of electric motors and internal combustion engines,as are fuel cell vehicles using pollution-free hydrogen as a fuel.

Critics,on the other hand,argue that when regulations are too restrictive and focused too closely around one technological solution,as happened with the battery electric vehicles (BEV), resources are drawn from other options which,although not truly zero emission, adequately tackle the underlying problem of local emissions.The development of advanced battery technology, the key component of BEV, failed to keep pace with early expectations. By 1996 CARB were forced to modify the mandate. Initially, the mandate was modified to abandon intermediate staged targets whilst retaining the 2003 target. More recently under LEV II,ZEV-like vehicles may qualify to earn a ZEV allowance of between 0.2 and 1.0 per vehicle. Vehicles that qualify for a ZEV allowance of 1.0 are known a full ZEV allowance vehicles. Vehicles that qualify for a ZEV allowance of between 0.2 and 1.0 are known as partial ZEV allowance vehicles,or PZEVs. Under these rule it is possible that vehicle with no EV components can qualify for some partial ZEV credit,but only hybrid EVs can generate more than 0.4 credits.

CARB has thus responded to some of the limitations of the original mandate with a more flexible, though arguably more complex,set of regulations that confirms the key role of the ZEV as an essential part of the State's long term air quality strategy but address some of the rigidities in the original regulations. In particular, the modifications aim to communicate a 'clear and consistent' message.This is to maintain the "true" ZEV component by providing a market opportunity for today's zero emission vehicles while gradually making the mandate more ambitious over time;and more generally to encourage the development of advanced propulsion technologies.

b Financial Support for Innovation

The 'traditional' linear model of the relationship between research and development and innovation:'R&D in = innovation out' and therefore that 'more R&D in = more innovation out' has been shown to be simplistic and inaccurate. There is now far more emphasis on continual feedback between the various phases of technology development from basic research through to commercialisation, on the discoveries and improvements arising from investment and operating experience (learning-by-doing), and on networks for innovation (see the POST report on clean technologies[15]). The new paradigm of market liberalisation and 'arm's length regulation' has also required governments to rethink their role in fostering R&D. As with the standard instruments of environmental policy, more direct instruments for stimulating innovation discussed here can be expected to have a significant influence on R&D policies in industry. But is this sufficient?

[15] Parliamentary Office of Science and Technology (POST) (2000), Cleaning Up? Stimulating innovation in environmental technology.

(i) Public support for R&D

Again the issue is not whether R&D will be stimulated by the standard instruments of environmental policy, but whether it will be stimulated optimally, and enable problems to be solved sooner than would otherwise be the case. Industry representatives stressed the importance of innovation in facilitating abatement and reducing costs (see Box 3), and argued that the commercial sector cannot be expected to deliver such innovations alone - especially in such areas as climate change, where the technological and financial risks are appreciable. They also stressed the need for "publicly supported, freely available research in the higher education sector to provide both the building blocks and the human capital required." All industrial countries, not least the United States, which is arguably the most market oriented in its policies, and the UK in its recent White Paper on Science and Innovation, recognise the importance of public support for R&D, including research in the higher education sector to develop new generations of researchers. R&D to support environmental innovation is no exception, and the main debate concerns the extent and nature of the support that is required.

Despite recent and welcome increases in public spending on education and research and the promise of more to come in the recent White Paper, the UK still lags far behind all major competitor countries on per capita spending on R&D, at least in the energy and environment sectors. As several industry representatives emphasised, it will be necessary for the level of support to reflect international norms if the contributions of the UK science and engineering research communities to industry, and in the public sector, are to be able to compete with those of other countries.

(ii) 'Back-loading' support for innovation.

Another approach is to offer direct benefit to innovators, without 'picking winners', through prizes for technologies that secure particular environmental objectives. The late Professor Bob Hill often suggested this for the person or company that invented a battery or energy storage system with a high energy density and storage capacity, such that the 'intermittency' problem associated with solar and wind energy would be solved economicaly. The merits of such a policy are that it would provide a high profile launch pad for invention - an incentive to develop ideas that are far from commercial viability, but which can subsequently be taken up and developed further.

The main disadvantage of back-loading is that financial prizes do not bring resources to bear on the problem of access to capital in the early phases of innovation, when costs and risks are high. On the other hand, it need not be restricted to a financial prize. It may be oriented towards the creation of market niches, the reward being a secure selling environment for successful innovators that allows for further innovation-e.g. through public procurement.

One option for backloaded support is public procurement, which may be used in several ways. The most familiar one is the purchase of 'best-practise' technologies or their outputs by public services, perhaps with a small premium for near commercial products. This helps to provide a secure market and gain the benefits of 'learning by doing'. US State and Federal commitments to purchase wind-generated electricity through the Wind Powering America scheme is an example. Public procurement may also be used for educational purposes and the demonstration of innovative technologies - a large-scale building integrated PV project on a high profile new public sector building for example, or alternatively a larger number of small-scale projects in schools and public places.

(iii) Tax incentives and credits for innovation.

As discussed earlier, there is much evidence that the costs of new technologies decline over time as investment and operating experience is accumulated.The implication is that,especially in the early phases of technology development,when the 'learning curves' are steep, each investment has two kinds of benefits:

- the direct economic and environmental benefits of deploying the technology itself;
- a contribution to cost reductions and improvements in abatement efficiency, which are felt in future investments.These are the positive externalities of 'learning-by-doing'.They are the present value of the product of the contribution of each investment to future reductions in costs (derived from the slopes of the cost curves) and the volume of future use (which can be a large quantity for emerging technologies in a rapidly growing market), plus the environmental benefits arising from improvements in abatement efficiencies and cost reductions.

Academic analysis of environmental policies has widely concentrated on the first benefit but, outside the engineering-economic literature, has almost completely neglected the second,arguably more important,benefit.Nevertheless,technology support policies of one form or another are pursued in most countries.

In the UK,the proposed capital subsidies for offshore wind and energy crops,in addition to the 'near commercial' support available through the Renewables Obligation,is a first step in policies to develop technologies further from the market. The recycling of Climate Change Levy revenues for capital allowances for firms investing in energy efficiency improvements could be built upon and extended to also include more innovative low carbon technologies.This would stimulate the development and use of more innovative technologies by reducing the risks associated with such investment and would enable investors to 'lever' the allowance through private equity and commercial credits.The UK Enhanced Capital Allowance scheme was based,in part,on experience from the Netherlands,where a tax incentive, in the form of accelerated depreciation,is used in this way to support small enterprise investments in renewable energy.

Economic analysis of environmental policy has widely neglected the positive externalities of environmental innovation, and focused exclusively on the negative externalities of pollution; but we need to recognise the former as well as the latter.

The ways by which innovation may be supported through tax incentives are many and varied,and the schemes and sectors to which they may be applied too numerous to discuss in a short report. Aside from tax incentives,another means by which a wide range of small and large scale innovations might by supported in the UK would be to consolidate existing environmental finance and subsidy schemes - for example, the capital allowances for energy saving investments,the landfill tax credit scheme, and other allowances - into a single fund that would use both the private sector and local government authorities as conduits for its applications.This would give extensive outreach to small,medium and large scale activities throughout the country;it would also give the policy considerable financial leverage. Let us consider this option further.

(iv) A National Environment Facility?

A National Environment Facility, akin to the Global Environment Facility (GEF, the financing arm of the UN Framework Convention on Climate Change), would provide a means by which finance for environmental innovation could be managed and channelled.This could build on and develop many of the features planned to be incorporated into the Carbon Trust,which will provide support for low-carbon technologies. The essential features of such a Facility might be as follows:

i) The grant finance provided by the Facility is blended with finance provided by commercial banks, investment banks and finance houses,private industry, and the equity contributions of the user. Depending on the case, Local or Regional Development Authorities (RDAs) also provide further investment incentives, related to their own environmental and development priorities - this links into both LA21 and RDA sustainable development strategies.The actual blend of finance varies with the case, with near-commercial projects using a small amount of subsidy to lever larger investment resources (say 10:1) whilst more ventures involving technologies in earlier phases of development and which are higher up the cost curves, receive proportionally more on grant support (perhaps as high as 2:1).Thus support is available for both near-commercial and more far-reaching innovations.

ii) The finance is available to large numbers of small-scale as well as to medium- and large-scale investments - e.g. for uses of renewable energy in households and small enterprises and establishments.The finance of small scale applications is made possible through the use of the branch networks of commercial banks,building societies,finance companies,and the retail outlets of the companies involved with the technology. Manufacturers (small and large) of environmentally innovative products and processes are also eligible.

iii) The appraisal and supervision procedures,depending on the case, are those of the private banks,private investors or the local authorities.The role of the Government is one of oversight and evaluation,not appraisal or supervision.This minimises bureaucracy and ensures objectivity in project selection and assessments of the capacity of the projects to repay the unsubsidised portion of the costs.The Governments are thus not involved in 'picking winners',only in setting the ground rules,which include defining general categories of projects eligible for finance.

iv) A wide outreach,supported through educational programmes,information packages and workshops for potential users. To draw on the GEF example, finance for one million solar home systems developing countries has been made available in recent years,and a large number of other renewable energy and energy efficiency projects.

v) The Facility is adequately resourced (short and long term options for financing such a facility are explored below).This means that very large numbers of small scale projects can be financed,such that participating banks and industries can plan to develop significant portfolios;this greatly reduces the transactions costs of 'doing business' with households and small enterprises,and encourages the development of supporting services.At the same time, medium and larger scale projects are encouraged.

There are thus good reasons for exploring the case for the establishment of a National Environment Facility on the above lines.The banks,however, may fear being drawn into a system of subsidised credit,which would entail extra administrative costs and the dangers of funds being diverted.What now needs to be explored is whether the advantages,plus those of engaging a wider community of financial expertise in finding innovative solutions to environmental problems of some importance, outweigh the drawbacks.

(v) Hypothecation of environmental user charges or taxes to environmental innovation

Every new environmental tax in the UK already has an element of hypothecation-the landfill levy, the climate change levy, road congestion charges,and the aggregates tax, for example. Despite the arguments of some economists against hypothecation,the political and economic advantages of environmental taxes being seen to be used to environmental ends are appreciable.They are now an important and growing source of funding for innovation,which the participants of the Workshops supported. [16]

c Other Areas of Policy

(i) Science Policy [17]

Knowledge production is critical to innovation. Policies to encourage innovation therefore need to be integrated with policies to support the production of knowledge. Traditionally this has included science policy alone, operating primarily through the funding of research in universities and in industry.

In promoting the innovation of 'sustainable technologies' support through the traditional institutions of science may no longer be sufficient, for two reasons. First,the shaping and acceptance of new technologies today depends on a more interactive and participative form of knowledge production.[18] The 'linear' model of innovation in which an environmental problem is identified,a technical 'solution' is developed and a process of wider diffusion into the market begins, is widely recognised to have broken down. Scientific knowledge about environmental problems is frequently uncertain and contested,while technical solutions need to be adapted to the needs, attitudes and behaviours of multiple and diverse actors. The twin problems of dissent and diversity need to be seen as normal aspects of innovation,and the best response is to bring a wider range of actors into the process of innovating and shaping new technologies. Second,the nature of knowledge production is itself changing and become more distributed. While traditional science has a critical role to play in enabling and evaluating new more sustainable technologies,other more

[16] Hypothecation was also supported by the Marshall Report in 1998 on the use of economic instruments for environmental policy.

[17] This section was written by Frans Berkhout,SPRU, University of Sussex.

[18] The term interactive research has been coined to refer to '...a style of activity where researchers,funding agencies and 'user groups' interact throughout the entire research process,including the definition of the research agenda,project selection,project execution and the application of research insights.Research users include policymakers,planners,business, non-governmental organisations and others who benefit from the products of research.' ESRC Global Environmental Change Programme, Designing 'interactive' environmental research for wider social relevance, Special Briefing No 4,May 1999.

distributed forms of knowledge in industry and civil society will also have a major role to play. Against this broader context of a need for greater interactivity, science policy in support of environmental innovation should have a number of features:

i) Risk, uncertainty and new technologies: All new technologies, including those deemed 'sustainable', have social and environmental consequences, some of them unforeseen. For instance, there is a tension between efforts to reverse 'holes' in stratospheric ozone above the poles or clean air policies and climate change policy. Less ozone, and more sulphur dioxide and soot particles, appear to lead to greater cooling of the earth's atmosphere.[19] Research into potentially negative impacts needs to be carried out in parallel with research that will provide the knowledge and techniques from which new technologies will grow.

ii) Encouraging diverse technical options: There are many technological responses to the broad objective of sustainability. Renewable energy supply technologies alone include a wide variety of different alternatives, but this variety is also a feature of other technologies. Moreover, more sustainable techniques tend increasingly to be characterised as 'services' that are better adapted to local conditions and market demand. These services will tend to be delivered through more distributed, smaller-scale technologies integrated into radically different infrastructures. Diverse niches exist there for sustainable technical solutions. To match this, science policy therefore needs to encourage the widest possible diversity of research activity. In some domains it will be possible to achieve this within the UK alone; in others it will require the further strengthening of European and international research networks.

iii) Long-term commitment: As this paper stresses, long time-lags frequently exist between the development of a technical concept bringing environmental and economic advantages, and its wider diffusion into the economy. Research capabilities on which sustainable technologies will be based need long-term support to continue to generate a flow of ideas and knowledge, and to remain a strong partner in the interactive mode of knowledge production outlined above.

[19] IPCC, Third Assessment Report, WG1, January 2001.

(ii) Political leadership & the role of strategic state intervention:

Industry representatives at the first Workshop especially emphasised the importance of clear long-term signals-of 'leadership from policymakers'-and commented on the influence of expectations about future policies in shaping their investment plans. A good example is that a voluntary carbon emissions trading scheme, set up by the Advisory Committee on Business and the Environment, and building on the experience from BP's internal global emissions trading system, will come into operation next Spring. This is ahead of the expected setting up of global emissions trading programmes under the Kyoto Protocol, and the intention is to make UK business and the City international leaders in this area. Leadership is not a policy option in itself; rather it provides the basis for more specific policy options and creates expectations on which industry decisions can be based. Broad and aspirational goal and target setting are one aspect of this, and underpin more specific targets and obligations. Clear commitments that financial resources will be made available is another, and again underpin more specific measures. Governments can also take the lead in creating knowledge and institutional networks for innovation.

There is a danger that aspects of such policy support could be seen as an attempt to 'pick winners', something UK policy has explicitly set out to avoid since the 1980s. Many Workshop participants believe that such an institutionalised objection to any strategic intervention in technology development is unhelpful and inappropriate in the context of the options discussed here. There are a number of reasons for this.

Firstly, many countries have pursued successful programmes based on a sound assessment of technology potential - wind energy in Denmark, Spain and Germany and fuel cells/hydrogen systems in Japan and Canada being clear examples, and there are many others outside the environmental field. Secondly, an element of technology assessment is essential to many established policy options - target setting for example, or R&D priorities. Thirdly, strategic support has in fact been provided to several industries in recent years, despite the 'ban' on picking winners; clean coal and aerospace are current examples. Finally, to avoid direct support for environmental innovation on these grounds would fail to address the risks inherent in the development of technologies to address uncertain and risky environmental problems; and it would lead both to a loss of the positive externalities of innovation and to environmental problems being solved later not sooner. Past failures in the UK may have more to do with the way in which projects were conceived and managed by nationalised industries and government departments, with little commercial accountability and little private participation.There was also a propensity for large projects and programmes.By contrast the options and instruments discussed here are well-suited to support a diverse portfolio of small,medium and large scale activities;entail public and private interaction in the choice of technologies developed; rely on a range of 'market tests';and ensure regular feedback on results.

(iii) Producer responsibility

Producer responsibility is a legislative mechanism which makes the manufacturer of a product responsible for some or all of the costs generated through the product's life cycle - including final disposal. To offset these new liabilities,manufacturers may add the costs on to the product's purchase price. This policy instrument is growing in importance. The UK has already signed up to the EU Packaging Waste Directive. This requires larger companies to recover 52% of the packaging waste they generate by 2001,with at least half this obligation to be met by recycling.Similar producer responsibility initiatives,which will apply to the makers of vehicles,electrical and electronic goods,and batteries,are currently being negotiated at an EU level.

The main idea is that making producers responsible for the end-of-life disposal costs of their products will provide a powerful incentive for them to find innovative ways of delivering service to the consumer using fewer and less hazardous materials. For example, companies like Xerox now sell photocopying services to customers by leasing photocopying machines,which they then take back and recycle the parts at the end of the machine's life.

In addition to providing the regulatory stick of producer responsibility obligations,there is a case for providing tax breaks to help businesses fund the retrieval costs of meeting their new recycling targets. Together, these measures would help make recycled materials competitive with virgin alternatives.

(iv) Environmental instruments, exports and foreign investment

Two factors require the UK to examine its structure of incentives for environmental innovation opportunities for foreign investment and exports.The first is the rapid growth of markets in environmental technologies world-wide in response to tightening environmental policies and economic growth.The second is the opportunity for trade and investment in the new non-carbon technologies that will required to address global warming.As noted earlier, the future scale of the world's markets will be enormous.

International instruments of policy currently in place or under development,such as the Clean Development Mechanism,the Global Environment Facility, and tradable permits and offset programmes,will generate new opportunities for investments in environmental technologies - though all such policies are (rightly) bound to be neutral internationally. However, UK policies to support environmental innovation need to go beyond this.They need to structure incentives for innovation,as other countries do, and within international agreements on tariffs,trade and investment,such that UK industries will be supported,not disfavoured.All the instruments discussed above can be tailored to this end if the principle is accepted.It is countries that have supported innovation and the development of new environmental technologies directly that will be better placed to compete in foreign markets relative to those countries that have not.

(v) Consultation and participation

As with other types of innovation,environmental innovations are likely to challenge current interests and to be potentially vulnerable to public scepticism or even hostility. Much of the work undertaken under the ESRC's Global Environmental Change Programme, for example the research by Andy Stirling and associates on perceptions of GM crops[20], has highlighted the importance of consultation and participation of all interested groups in public policy decisions.Such consultation and participation can help to incorporate a range of values and interests,and provides a way of dealing with inevitable uncertainties and risks involved in environmental innovation.

[20] Stirling and Mayer (1999), Re-thinking Risk:A pilot multi-criteria mapping of a genetically modified crop in agricultural systems in the UK,SPRU Report No. 21,University of Sussex,Brighton.

4 Conclusions and Recommendations

Two main conclusions emerged from the Workshops and the consultation process:

The first was that the 'standard' instruments of UK environmental policy - primarily regulations and taxes on pollution - have historically been important drivers of environmental improvement,but fall short of a desirable policy:

- The times taken to develop new technologies and practices and incorporate them into everyday economic activity are appreciable.The lag between the implementation of a standard policy and the market penetration of a new technology is typically on the order of 25 to 50 years.Related to this:
- Because it takes time to develop and implement low pollution alternatives,the short-run elasticities of response to standard policy instruments are small. Thus instruments like environmental taxes raise revenues,and raise hackles,while having limited short-term returns in terms of pollution abatement.This can give rise to political and economic difficulties which hamper policymaking and reduce the pace of change. Of course, in the longer term such policies do send the right signals and engender change. Direct support for innovation and technology development can accelerate the process.Further, by creating options it can facilitate a political and public commitment to a constructive approach - combining short term acceptability with longer term objectives.

In short,UK environmental policy should address the importance of innovation.

The second conclusion was that UK innovation policy has not given sufficient priority to environmental innovation.Although the UK does have instruments focussed on environmental innovation directly, they are too focussed on the near-term,near-commercial opportunities and less on practices that require further development but have greater long-term promise.The upshot is a propensity to import innovations from - to 'export innovation' to - countries that provide incentives in the earlier phases of technology development,as happened with NFFO.The conclusions from this are, again,twofold:

- Technology support policies need to look to the longer term and provide mechanisms,including finance, by which technologies currently in need of considerable development may be brought forward.Such support needs to target a range of barriers to innovation,including those faced by smaller companies.Existing plans, for example the capital subsidies envisaged under the Renewables Obligation,provide important first steps,which may be built upon.

- Support for fundamental R&D, and the priority given to support for environmental innovation amongst other innovation priorities needs to be adequate, at least reflecting international norms for R&D expenditure, and ideally placing sustainable technology development on a par with other priorities,such as bio-tech and information technology.

In short,UK innovation policy can and should do more to address the importance of the environment.It is encouraging that a number of recent policy pronouncements and Government papers cited above have begun to move in this direction.

Recommendations: next steps for policy

There is,of course, further work to be done in defining a complete set of policies for environmental innovation.In the final Workshop, the following were discussed:

1. Apply leadership and long-term targets:

The importance of expectations in influencing the direction of innovation was emphasised frequently in the Workshops, and a high level political commitment to the development of the UK's capacity in environmental innovative technology is key to this. High level commitment is essential, with clear targets for the development of a number of key innovative technologies that will benefit from learning-by-doing and adequate funding to ensure that this is achieved.Such a high level approach would build upon the existing intellectual basis:the Competitiveness and Science and Innovation White Papers,Sustainable Technologies Initiative, the New and Renewable Energy Programme and Sustainable Development Strategies.

[21] Berkhout,Eames and Skea (1999),Environmental Futures, Foresight,Office of Science and Technology

[22] DTI (2000),DTI Sustainable Development Strategy

There is a need to set targets for the development of sets of technologies. A costing of the development of options identified in studies such as the scenarios developed under the Foresight Programme[21] would provide a good basis.

2. Use investment incentives:

Ensure that existing funds for the support of environmental technology deployment and development focus on innovative technologies in the earlier phases of development,as well as on near-commercial options.

In order to make for a coherent and higher profile approach to environmental innovation this could be developed a step further:

3. Consolidation of existing support for environmental technology development into a common fund:

This could include redirection of some of the revenues currently accruing through the Landfill Tax Credit Scheme, and the CCL revenues for energy efficiency and low carbon technologies. Such a fund was referred to above as a National Environment Facility or Fund, but whatever it might be called it would have the following features:

- Large and small companies and large and small applications would be supported.
- Support for both technology development and technology diffusion.
- Financial leverage. Finance provided by fund would be blended with that provided by private, commercial sources.Leverage would vary, being higher for those with near-term and lower for those with long-term promise.
- A delegation of responsibilities for appraisal and supervision from government to those of the banks and others involved in the projects.The role of government would be oversight and setting ground rules only.

The indicators recently announced in the DTI's Sustainable Development Strategy[22], for greenhouse gas emissions relative to GDP and waste disposal relative to GDP, might provide an initial focus for activity. Funding would obviously depend on resources available, and the suggestion was made that it would begin with a modest base and evolve with experience. But it would need to be large enough to encourage the participating institutions to develop significant portfolios so as to reduce the costs per transaction of dealing with large numbers of often small-scale projects.Future funding could be provided by drawing a share of a number of hypothecated and environmentally oriented levies,such as the Landfill tax,CCL,and congestion charges.

4. The instigation of a prize for meritorious innovations that solve especially difficult problems economically:

For example, the development of an energy storage system with a high energy density and storage capacity to solve 'intermittency' problem of renewable generation.

5. Use public procurement policies to encourage the demonstration and use of innovative technologies and for educational purposes.

6. Invest in research and development:

Especially in energy and the development of 'climate friendly' technologies,current UK public R&D expenditures are appreciably below international norms,having declined by a factor of ten since the privatisation of the energy industry in the late '80s-early '90s. Yet in few areas is the creation of options more difficult or more important.The point has been made many times,that if the UK is to compete in the development of new technologies for addressing environmental problems it will need to reverse this decline. The establishment of the Carbon Trust is an important step in this direction.

Building on the Workshops

The Workshops followed an established tradition of the ESRC-GEC programme of engaging academics,industry and government departments in the exchange of ideas on policy. Although the programme itself has come to an end,a continuation of such exchanges would provide a forum for the evaluation of experiences in the UK and abroad,and through this contribute to the development of future policies.It was suggested that we should seek to create a network on the subject to encourage debate, engage stakeholders and refine ideas for policy;develop a wider programme of outreach and education;establish links with the foresight programmes;and involve other stakeholders such as industry associations,local governments and the Regional Development Authorities.

Annex 1. Workshop participants

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Christopher Anastasi	Head of Environment,British Energy Plc
Dennis Anderson	Professor of Energy Policy & ICCEPT Director, Imperial College, GECP Fellow
Robin Bailey	Director, Venus Internet Ltd
Colin Beesley	Head of Environment,Rolls Royce Plc
Frans Berkhout	Co-Director, GECP, University of Sussex
Piers Bisson	Environmental Tax Team,HM Treasury
Dan Bloomfield	Sustainability Officer, Greater London Authority
Andrew Burchell	Head of Sustainable Development Unit,DETR
Tom Burke	Visiting Professor in Environmental Policy, Imperial College
Will Cavendish	Head of Policy, the Labour Party & Visiting Fellow, ICCEPT
Chris Clark	Principal Fellow, Imperial College
Paul Ekins	Director, Forum for the Future & Keele University
Herbert Enmarch-Williams	Lawrence Jones Solicitors & T3 Ltd
Tim Foxon	Research Associate, Imperial College
Paul Freund	Director, International Energy Agency Greenhouse Gas Programme
Jack Frost	Business Manager, Fuel Cells, Johnson Matthey Plc
Chris Foster	CROMTEC, UMIST Management School
Robert Gross	Research Associate and ICCEPT Co-ordinator, Imperial College
Michael Grubb	Professor of Climate Change and Energy Policy, Imperial College,Associate Fellow, RIIA
Brian Hackland	Environmental Policy advisor, No. 10 Policy Unit
Martin Hession	Lecturer in Environmental Law and Policy, Imperial College
Andrew Holder	Agriculture, Environment and Rural Affairs, HM Treasury
Terence Illot	Head ofEnvironment,BusinessandConsumers, DETR
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Gary Kass	Parliamentary Office for Science and Technology
Matthew Knight	Head of Environmental Technology, London Business Innovation Centre
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Clive Maxwell	Environmental Tax Team,HM Treasury
Peter Mucci	Innovation Unit,DTI
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Peter Pearson	Director, Environmental Policy and Management Group, Imperial College, GECP Fellow
Jason Perks	Director, sd3 Consultants Ltd (Sustainability Adviser to Vauxhall)
Jacky Pett	Business & Industry Policy Co-ordinator, WWF-UK
William Price	Productivity Team,HM Treasury
Douglas Robinson	Environment Unit,DTI
Paul Rutter	Special Advisor to Green Operations, BP Amoco Plc
Alister Scott	Assistant Director, GECP, University of Sussex
Jim Skea	Director, Policy Studies Institute, Former Director, GECP
Rita van der Vorst	Lecturer and Head of Clean Technology Group, Imperial College
Darren Watson	Advanced Engineering Centre, Rolls Royce

Annex 2. Sources and notes for Table 1

Electricity Generation: Based on OECD (1989), Asian Development Bank (1991), Tavoulareas and Charpentier (1995), and Hall,et al.(1995). Descriptions of the technologies can be found in these sources,and also in any good text on environmental engineering, for example in Kiely (1997).The term 'polluting practice' here refers to a coal-fired boiler with mechanical controls. The term 'clean coal technologies' is (not unmerited) public relations short-hand for a range of technologies such as the following: electrostatic precipitators and bag-house filters for removing particulate matter emissions;flue-gas desulphurisation in coal-fired power plant; fluidised bed combustion (FBC) of coal (removes sulphur and raises thermal efficiencies);integrated coal-gasification,combined cycle (IGCC) technologies,which can also be used to remove sulphur and raise efficiencies; and catalytic reduction of NOx or so-called low-NOx burners,which reduce NOx by lowering combustion temperatures. Costs are expressed as a percentage of electricity supply costs, for which 8 cents per kWh is taken to be a typical value. The end-of-pipe technologies (desulphurisation and PM removal) generally raise costs,which explains the upper limits to incremental costs shown; gas-fired plant have lower costs for a number of reasons,the principal ones being short lead-times and higher thermal efficiencies,which explains the negative cost figure shown relative to coal fired plant. Note, however, that the IGCC and FBC are also expected to raise efficiencies and reduce costs.

Motor Vehicle Emissions. The estimates are based on the extensive reviews by Ross (1994) and Faiz,et al.(1996) and the data quoted by Ross from the American Manufacturers Automobile Association (1993). For petrol engines,the costs of three-way catalysts are quoted by Faiz et.al.to be $630,who also notes that there is a loss of fuel economy of 5%. Electronic fuel injection raises the costs to $800,but improves the fuel economy by 5%. Taking the cost of a car to be $20,000,the pre-tax cost of fuel $1 per gallon,the fuel consumption 25 m.p.g., average miles per year 10,000,the lifetime of the cars 15 years,and the discount rate 10%,the marginal costs of achieving these abatement efficiencies are 3 percent of the expenditures on the vehicle with and 3.5% without electronic fuel injection. For diesel engines options for reducing emissions include a range of innovations in engine design and fuel formulations,in which improvements in fuel efficiency help to offset the higher capital costs.Faiz et.al., pp. 76-79 provide details.In a study which looked at alternative fuels for the abatement of urban pollution and CO2, Krupnick, et al.(19993) arrive at not-dissimilar cost estimates to those shown here.

There is a qualification to be made regarding the pollution from vehicles in congested areas,which is that frequent stopping and starting and rapid acceleration greatly add to emission rates.While dynamometer tests attempt to allow for this,Ross (op. cit.,p 76) cautions that,although "some progress has been made in improving ambient air quality in major metropolitan areas (in the US),most of these areas still do not meet clean air standards. An important part of the cause of this shortfall ....is that actual automotive emissions per mile are much higher than those measured in the regulatory test." Another complication is that air quality is a function not only of emissions,but of their concentration,which in turn varies with topography, local weather and climate, urban population densities and building structures.

Household fuels: Smith (1993) provides data on both indoor and outdoor concentrations in developing and developed countries. His review of particular cases (in India,Papua and New Guinea, Nepal,China and several others),shows that the levels of indoor pollution vary from under 2000 to over 18,000 (ug/m^3, or several thousand times the levels experienced in the industrial countries using modern fuels.The switch to modern fuels,especially piped gas or LPG not only reduces indoor pollution to very low levels, but is justified terms of its private economic benefits. Consumers' willingness-to-pay for gas exceeds the costs of supply, and supply expansion has long been justified without reference to its benefits for health once it is substituted for wood or coal as a domestic fuel. Hence the negative cost estimate shown in the fourth column.See also World Bank (1996).

Household fuels and soil erosion. The use of fuelwood and dung for cooking is not the only (and sometimes not the major) source of soil erosion,but it has long been known to be an important one. It is a problem well remedied through agroforestry practices and related soil conservation practices,which actually have economically beneficial effects on crop yields sufficient to justify the investments even ignoring the environmental benefits (Anderson (1989),Brandle et.al (1988),Gregerson et.al.(1989), Doolette and Smyle (1990),Magrath (1990),Grimshaw and Helfer 1995),and Current et.al.(1995).Further they are capable of replenishing soils and are commonly used for land reclamation; hence the index in the third column has a lower limit of <0.

Renewable Energy for Reducing CO_2 Emissions. The estimates are adjusted to 10% discount rates,and are based on the following reviews,which themselves collectively have reviewed over 500 papers and studies;see Mock,et al.(1997) on geothermal,Larson (1993) on biomass,Ahmed (1994) on several technologies, Gregory (1998), World Bank (1996) and Anderson (1997). Reference should be made to these sources for details and qualifications.

Municipal Wastewater Treatment: Acronyms:BOD = biological oxygen demand,SS = suspended solids,TP = total phosphorous, and TN = total nitrogen. The texts of Kiely (1997) and Metcalf & Eddy (1991) note that the pollution abatement levels achieved in many regions can be much higher than indicated in the above table. For municipal waste-water plant with full-settlement, activated sludge processes,combined biological and nitrogen removal,and chemical disinfection the residual levels of pollutants in the effluents relative to the influents of such plants are as follows: faecal coliform 0%,suspended solids <1%,BOD <0.3%, phosphorous <10%,nitrogen <2%. The estimates shown here are based on West European and US experience. See Europe's Environment:Statistical Compendium, WQI No. 4,1993,taken from a report by Laszlo Somlyody for the Environmental Action Programme for Central and Eastern Europe, The World Bank. The footnotes to the table say that all the technologies incorporate a primary sedimentation tank and, for biological treatment, an activated sludge process. Chemically enhanced primary treatment is also assumed plus denitrification in the tertiary stage. The estimates of costs as a percentage of value added in a metropolitan area is based on data on the above costs per cubic metre times estimates of volumes of water use in cities,see Metcalf & Eddy (1991).

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