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Working Group on Innovation and Technology Policy

TECHNOLOGY FORESIGHT AND SUSTAINABLE DEVELOPMENT: PROCEEDINGS OF THE BUDAPEST WORKSHOP 11 DECEMBER 1998

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FOREWORD

There is a growing interest in technology foresight in the OECD Member countries because of the need to set priority in research and development in the context of the increasing cost of research and the tightening public budget for research. R&D efforts also need to be directed towards fulfilling social needs at the same time as providing sources of innovations that contribute to sustainable growth, competitiveness and job creation. Sustainable development is a future need that is accorded increasing importance by Governments of OECD Member countries. As the papers contained in this document show, technology foresight is a tool that can be used to match future needs with the supply of science and technology.

Technology is one of the areas that comprise the OECD horizontal programme on Sustainable Development. The OECD Committee for Scientific and Technological Policy and the Working Party on Innovation and Technology Policy are actively engaged in contributing to the programme. The papers contained in this document were presented at the OECD-OMFB (Hungarian National Committee for Technological Development) Workshop on Technology Foresight for Sustainable Development, held in Budapest on 11 December 1998. The papers discuss a range of issues related to technology foresight and environmental sustainability. In addition to the discussion of foresight methodology relevant to environmental sustainability, results of the major foresight studies, including key future technologies that contribute to sustainable development and the policy relevance and issues related to the implementation of results of technology foresight for sustainable development, are discussed.

EXECUTIVE SUMMARY

As a part of the activities of the Working Party on Innovation and Technology Policy, a workshop was held in Budapest on 11 December 1998, under the joint sponsorship of the Hungarian National Committee for Technological Development (OMFB) and the OECD, on Technology Foresight for Sustainable Development, with the participation of experts and officials from more than a dozen OECD Member countries. This document includes the nine papers presented at the workshop. The papers discuss issues surrounding foresight methodology for environmental sustainability, results of some recent foresight studies including key future technologies for sustainable development, and policy relevance and implementation of foresight results as they relate to achieving environmental objectives. There is a growing interest in technology foresight in the OECD Member countries for priority setting in research and for directing research and development efforts to be more responsive to future needs. Sustainable development is a future need along with enhancing growth, competitiveness, and job creation, to which Governments of OECD Member countries attach increasing importance. Technology foresight is a tool that can be used to match emerging technologies with future needs. The papers present useful insights into the nature of technologies relevant for the environment, problems of foresight methodology for environmental objectives, and issues in policy relevance and implementation of the results.

One clear trend that emerges from the papers is that the nature of the technologies that contribute to improved environmental performance has evolved over the last few decades. Some of the papers (Johnsen, Calenbuhr) refer to the narrow meaning of end-of-pipe technologies when using the term, “environmental technology” and point to their limited contribution to enhancing competitiveness while improving environmental performance. They stress the importance of a broader definition that includes process and product integrated cleaner, and more resource efficient technologies. Such a broader definition is used by the other authors when using the term environmental technology, and the recent shifts to such cleaner and resource efficient technologies are proving to contribute to the improvement, not only of environmental performance, but also economic performance, through cost saving and enhancing competitiveness and productivity growth of firms that develop and use them. Awareness is growing that innovations for environmental sustainability present an enormous area of business opportunities; hence, economic growth and job creation.

Such a change in the nature of environmental technologies makes them even more diffuse, as some authors stress (Kuntze, Fukasaku, Williams). Technologies that enhance environmental performance and sustainability are found in all established disciplinary areas and are applied in all industrial and infrastructure sectors. They are basically bound by their common objective of improving environmental sustainability. The diffuseness of technologies relevant for environmental sustainability points to the importance of an interdisciplinary approach in research and development, closer links between government, industry and universities not only in research but also in the application of some technologies. As Vollenbroek *et al.* suggest, technologies that enhance environmental sustainability work best when applied not as separate technologies but as technology systems. The interdisciplinary and intersectoral nature of environmental technologies point also to the importance of international co-operation in developing relevant technologies, as these papers stress. This is especially important when addressing global environmental issues.

Another point about technologies relevant for sustainability is that such technologies extend beyond technologies that produce or are embodied in tangible goods. Some papers point to the importance of organisational or “soft” innovations (Kuntze, Williams), and Calenbuhr cites examples of the sale of goods being replaced by services. This articulation of market demand for services provided by manufactured goods, rather than their ownership, has profound implications for environmental sustainability. Calenbuhr also gives examples of financial sector innovations that can have positive effects in inducing investments in environmental technologies. This points to the importance of an integrated approach not only for technologies in the industrial process, but also in designing policies to stimulate innovation in environmentally sustainable technologies. The integrated approach implies policy integration and coherence between research and technology policy on the one hand, and a number of other policy areas including environment, regulatory, fiscal and economic policies for the aim of improving environmental sustainability on the other.

In view of such a broad scope of technologies relevant for the environment, it is quite striking that the attempts at identifying some key future technologies for environmental amelioration discussed in some papers, (Kuntze, Stokes, Fukasaku, Williams) demonstrate remarkable convergence, despite the difference in the foresight methodologies on which such analyses are based. This implies that there is a consensus at the international level on the generic technologies and broad application areas that will serve the needs of sustainable development. The generic technology areas include information and communication technology, biotechnology, nano- and micro-scale technologies, and advanced materials. The application areas range from agriculture, water treatment, waste and hazardous substance treatment and management, vehicle technology, construction, cleaner industrial processes, and energy, to monitoring and counteracting global environmental changes.

Despite this remarkable agreement on the kinds of technologies that can be supplied for sustainable development objectives, most papers express extreme uncertainty about the prospects for realisation of such technologies on a significant scale. This is reflected in the recourse to scenario approach in assessing the extent of the market demand and the penetration of such environmentally sustainable technologies (Havas *et al.*; Dearing, Vollenbroek, *et al.*). This demonstrates that the extent of use of environmental technologies depends overwhelmingly on the kind of socio-economic system that will be in place in the future. The possible future scenarios of socio-economic evolution discussed in the papers differ considerably at first glance, but are all stereo-typical in a sense. The real world is likely to consist of a mixture of conflicting values and socio-economic trends rather than stereo-typical systems that scenarios tend to depict. In general, however, the scenarios discussed in the papers indicate that socio-economic systems that focus simply on more growth are likely to fail to implement environmental technologies and lead to an unsustainable future, and those that favour regional integration and co-prosperity between the regions of the world, while allowing pluralistic values and equitable growth, are likely to provide a larger market for environmental technologies, hence improving our chances to achieve a sustainable future.

Thus, the bottleneck for environmentally sustainable technological innovations, the authors agree, lies not in their supply, but in the lack of a market for them. This market pull factor is of utmost importance. Dearing goes as far as to say that “innovation is no use when there is no market for it”, because the market for environmental innovations, as it stands now, is still so precarious and inarticulate. Strengthening of the market pull is where public innovation policy can play a vital role. Here again, the importance of policy integration and coherence is underlined. As Vollenbroek *et al.* suggest, a high level of economic dynamism is necessary for achieving sustainable development, but this needs to be combined with articulated societal demand for environmentally efficient technology systems.

This brings us back to foresight methodology. Given current trends in general, and especially with foresight for sustainable development, the integration of market orientation seems to be a crucial component of foresight exercises. This is the part that the UK Foresight Programme attempted to integrate and reinforce. As Williams says, identifying future technologies was less important compared to the foresight process of bringing together the research base and the industry to consider together the opportunities and challenges for marketable innovations. The importance of foresight was in the process not in the prediction. Through this interactive process, proactive matching of supplies of technology with societal demand can be done.

The importance of an interactive process was stressed in the foresight exercises of smaller countries. As pointed out by Johnsen, the research base of smaller countries is often too small to design and implement foresight exercises such as the Delphi survey. In launching the new Norwegian Environment and Technology 2010 programme, the results of larger countries' foresight studies were used to identify future technologies, and within the country, the foresight exercise's focuses on generating interactive process involving government, research base, industry and societal groups. Similarly, the Dutch programme likewise drew upon the results of other foresight studies to identify technology options for sustainable development. The Hungarian foresight programme is designed to generate an interactive process for identifying research priorities in that country's relatively new socio-economic system, which is now also aspiring for integration into a newer regional socio-economic framework of the European Union: this is likely to give the country a more promising path to sustainable future. To be sure, there now exists a large pool of foresight studies made by larger countries (Japan, Germany, United Kingdom, United States, France) upon which other countries, especially newly industrialising ones, could draw.

As the papers in this document demonstrate, the value of technology foresight as a tool, therefore, is in its ability as a process to link the public research sector with industry in the substantive discussion of a desirable future and of marketable technologies. It is a tool that can identify and match technology supply with market demand, including demand for social objectives. When the foresight process is designed so that market opportunities are fully taken into account, it could make valuable contributions to realising sustainable development at the same time as dynamic growth and job creation.

ENVIRONMENT AND TECHNOLOGY 2010

by

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This is a strategic project carried out by the Research Council of Norway. Based on the acceptance of the changing character of the environmental challenges, a need for a forward-looking process has been identified to realign the research activity with the environmental and societal needs. The choice of project title carries two important messages; first of all the extension of the traditional concept of environmental technology into a scientific and intellectual topic highlighting the interaction between environment and technology. Second there is the slightly pragmatic and lowered ambition of *not* aiming for a 20-20 foresight, as in perfect vision, but settling for a more short-sighted, maybe somewhat skewed result as in 20-10.

The core ambition of this project is to revise and revitalise the handling of the environment and technology area both within the Research Council and between key players and sectors dealing with the topic. Such key players are ministries, industries, and the research community at large. Nominally the project will result in a proposal for a new way to organise and prioritise public support in the field, as well as extensive supporting analysis.

This paper will thus focus on the two main aspects of the project; the topic and the process. However strongly entwined, it is necessary to separate the two to be able to deal with the complexity involved. As anybody experienced in developing new solutions to environmental challenges will know, a perfect, but un-implemented technology is as good as none. The same is true for regulations and economic tools without reality checks.

Allow me, initially, a brief hindsight into the world of environmental technology and the related commercial optimism of the 1980s. In this context, environmental technology, to be distinguished from cleaner or greener products, covers products and solutions with a *main* purpose of removing or reducing environmental burdens. This initially involved traditional end-of-pipe treatment solutions and products, as well as monitoring systems and equipment, but now includes services and knowledge-based products and all shades of Cleaner Production.

Unlike most OECD countries, Norway has until now chosen to treat energy technology separately from environmental technology, due to its unique energy-base, with close to 100% hydroelectric power. Unlike most OECD countries the environmental impact from energy consumption in Norway is primarily linked to the landscape changes associated with the construction of power plants and is consequently of limited importance when new energy technologies are being discussed. With the advent of energy production from natural gas on Norwegian soil, the environment/energy relationship is however changing.

As the extent of environmental problems became fully documented, the predominant national and international view into the first half of the 90s was that environmental technology would be the dominating growth area of the near future. The market for treatment of emissions to water and air as well as contaminated ground, in combination with monitoring and enforcement systems was estimated at billions and billions of US dollars on a global scale. Such calculations were based on average installation costs and multiplied by the number of sources or sites to be dealt with.

The eventual difference between potential needs and the realised market volume was to a large extent disregarded as governments established publicly financed research and development programmes to help local industry capture market shares at home and abroad. With minor variations, the different initiatives were meant to encourage new technology-based solutions which would both solve environmental problems *and* provide profits and new employment opportunities.

Based on a thorough analysis of the national and international opportunities, the government of Norway chose the area of environmental technology as a National Priority Area in 1988. The Royal Norwegian Council for Scientific and Industrial Research was given the responsibility for initiating and co-ordinating support measures aimed at both “problem-owners” and “problem-solvers”. Through three subsequent user-driven R&D programmes the (renamed) Research Council of Norway has, over the past ten years, helped develop a number of commercially interesting products and systems as well as the related knowledge base and services.

The format of the programmes has varied somewhat over time, but has targeted national priority areas like offshore and marine activities, different industrial emissions, as well as the municipal challenges of wastewater and solid waste treatment. One of the main requirements for new projects has been a significant commercial potential either nationally or internationally. Another has been the close co-operation with leading national research facilities to ensure the continuous development of the scientific and technological knowledge base with a view to future projects. The support rate has varied between 25 and 50% depending on the type and content of the project.

The main beneficiaries of these programmes have consequently been established companies with a sound economic base mixed with a handful of venture-financed start-ups with “golden eggs” and miles of research on their hands. Later evaluations have shown that the priority areas identified in 1988 have not been the ones to attract most attention from the companies, mainly because the market mechanisms have been weak or lacking altogether. Based on financial reports and interviews with support recipients during and after the programmes, evaluations have shown a varying degree of market success from the supported product development. There are, however, a number of success stories both from a scientific and commercial point of view ranging from monitoring and decision support systems to effluent treatment and automatic waste handling technology. In addition there is the effect of knowledge building both within participating companies and the research facilities involved, an effect which is hard to quantify.

Arriving at the millennium there is, however, a strong feeling on all sides that the environmental challenges as well as the environmental policies have moved ahead, looking for a much more integrated set of solutions compared to the ones developed over the last two decades. Compared to the expectations of the 80s, the identifiable market for environmental technology has not reached the size or the “mature” status which was the basis for investments by governments and companies alike. This disappointing development can at least partially be ascribed to the wide use of alternatives to treatment systems and separate technological solutions.

The bitter experience in many environmental technology companies who have developed unique solutions is that there are at least three alternatives to investing in new technologies for any polluter/problem owner:

- Terminate the offending process or product.

- Move to cleaner production.

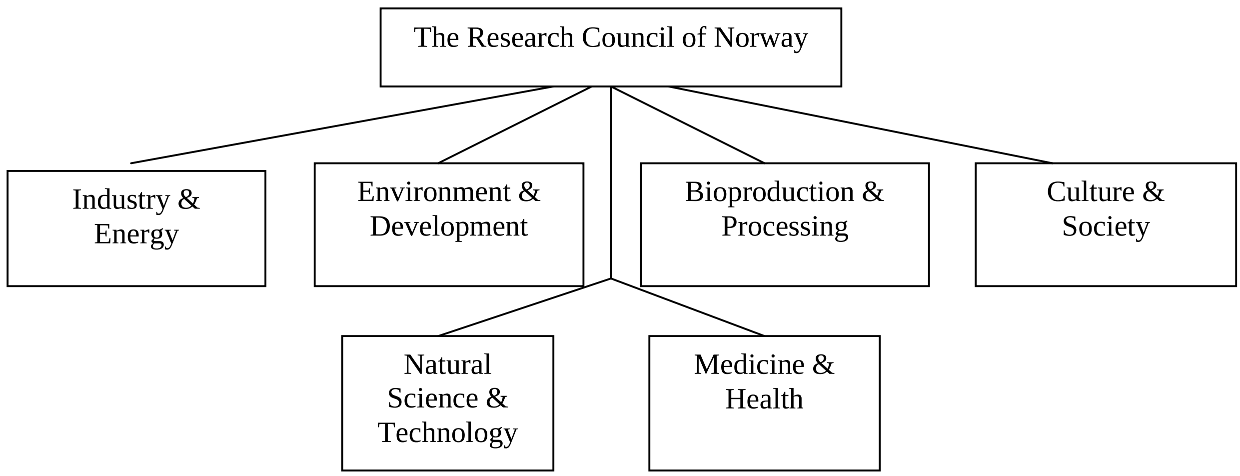
– Strike an extension deal with the authorities.

The latter choice may be found in most countries in different shades of white and grey. The economic arguments and the environmental and technological uncertainties are often given the benefit of the doubt reducing and extending in time the anticipated turnover from the development project. There are of course major and visible exceptions to this description, leaving some environmental technology companies with high profits and a similar market profile. The analysis of success factors associated with these companies is a topic in itself, which will not be discussed at this point.

A second problem, in terms of statistics, has been the increasing integration of environmental solutions into products, processes and organisation of activities. This development has made it virtually impossible to quantify the contents of environmental technology in any system apart from the end-of-pipe products. The industrial and public development towards outsourcing and turn-key solutions has in addition often left stand-alone solutions stranded in the competition with alternative integrated solutions developed by the traditional process or systems suppliers thus increasing the above problem.

Although these observations may be considered digressions from my main topic, they are in my view key factors in understanding and utilising the driving forces behind the future framework for technology development. They are also important arguments for changing the shape and goals of support measures as well as some of the definitions traditionally employed in this field.

As environment has become either a driving force or an important part of the framework for all types of research, the six organisational and topical Areas within the Research Council of Norway have all established research programmes and projects relevant to the environment.



For many purposes, some of which I will come back to, such activities ought to be inter-linked to relate to the actual environmental challenges, the user needs and the different types of research activities and programmes. Such a linking in itself is a worthy task for any bureaucrat. Combining it with the continuously dwindling financial resources allocated to research and the resulting struggle for attention between sectors, the task does appear to be one notch above the ordinary.

To complete the setting for the future-oriented work now being carried out, it is worth noting that Norway has a total population of 4.5 million and a share of the total international R&D activity of less than 0.1%. The thoughts of Delphi-studies or advanced scenario building quickly strand on human and financial limitations. Even the number of self-proclaimed experts is so limited that few topics would gather the necessary number of individuals to constitute a critical mass for such a process. A different path to enlightenment goes through the documentation from relevant projects and activities in other countries. To be of practical use, this knowledge, however, has to be augmented by a mapping based on "ground truth" in our own country.

This "ground truth" includes the positions and interests of different potentially financing ministries as well as political priorities. What is the role of government and its subsidiaries, and what are the most efficient tools? The need for policy relevance in choice of topics and targets is obvious, while the fulfilment of the strategic role of the Research Council has to be met through a long-term interaction with the basic policy processes within the Ministries.

Without drawing further parallels, I must, at this point, associate myself with Niccolo Machiavelli who, 485 years ago, already observed the following:

> *"It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new system. For the initiator has the enmity of all who would profit by the preservation of the old institutions and merely lukewarm defenders in those who would gain by the new ones."*

In spite of this, and with the blessing of the administration both in the Research Council and the Ministries of Industry and Environment, a one year project was established to provide a thorough basis for decisions both within the Research Council and in the Ministries.

Before going into the details of the project I would like to dwell further on the choice of title and the change of view implied by using "Environment and Technology" instead of Environmental technology. Primarily this change reflects a break with the traditional conception of technology through products as an external, easily identifiable tool for solving environmental problems. Water treatment plants, air emission filters and sensors for monitoring are core examples of the common understanding of environmental technology.

Developments of such solutions are easy to identify as separate, limited projects with more or less controllable parameters, customers and market opportunities and are consequently suited for traditional support programmes. To a large degree the markets and technology opportunities are the driving forces behind such programmes and investments by industry. As the environmental challenges change and the complexity of the problems increase it gets harder to identify a one-step cure for an illness. Like the medical profession, people involved with technology for the environment have to deal with the whole patient, not only develop a medicine for each symptom.

Without moving all the way to Gaia theories, the approach chosen is based on identifying the role of technology within priority areas of national and international environmental policy programmes. Considering the limited resources in personnel and financing, it is also important to look at key technologies and knowledge areas to invest in for the future, not only what will bring revenue over the next few years. Depending on the international strength of companies and research communities the view beyond the present market situation will also be influenced by differences in market strategies and positions.

"Environment and Technology" is more of a concept for an area of opportunities and commercial activities than a tool and product definition. It also eases the confusing border area between cleaner products, cleaner technologies, industrial ecology, environmental management and environmental technology. All the latter become tools and sub-tasks involving varying technology content and an increasing reliance on knowledge, services and organisational solutions.

To tackle this complex subject, our overall project has been split into six sub-projects:

- The future environmental challenges and the role of technology.
- Present research activities in Norway.
- Environmental policies and relevant governmental tools.
- The view of industry, both problem owners and solvers.
- The view of the research community.
- The view of the NGOs.

Once again, with limited time and resources, the choice of methodology was fairly simple: to utilise the internal future-oriented processes of the key organisations involved, including those of the Research Council itself. It must be observed that the whole operation of the Research Council in Norway is built on a system of external advisory boards, extending from the Main Board of the Council dealing with high level research strategies, down to the Programme Boards dealing with individual sectors and often applications.

Throughout the process of establishing new initiatives such as the present one, the board members at the different levels assume a double function: putting forward the views of their field or interest group, while introducing initiatives to their peers in business or research.

By challenging the organisations to present their views and reasons for priorities ten years ahead we are sufficiently removed in time to open up an interactive process between different players. Identifying highly qualified individuals as "process owners", information gathering and workshops are set up under each sub-topic. The link into the international scene is forged through industries competing in the global market, through individual scientists competing in an international knowledge market, and through the NGOs agenda.

In the field of environmental monitoring, there is the accepted view that measurement and analysis has no value if the results are not subsequently integrated into decision making. When looking to the near future the same applies to the present process. The fine balancing act between extrapolation of the past and creating an utopian future has to be observed. In our view, the key to this balance is to challenge leaders who have responsibility for developing their organisations well into the next millennium.

The future environmental challenges and the role of technology

As part of the work under this topic, and as an aid in the other processes, a list of topics has been established based on an analysis of the international and national consensus. Along with the globalisation of environmental policies, as well as commercial activities, this has mainly consisted in choosing "how to cut the cake". One can describe the future according to polluting source or substance, to recipient or, as we have chosen, to the resulting problem packaged in easy-to-communicate policy terms:

- Climate change.
- Food safety.

- Water resources.
- Urban environment.
- Production and consumption.
- Biodiversity.

The challenges are briefly defined and described by experts and panel discussions and hearings in different settings give rise to a view of the most likely role of technology. In some areas financial and organisational hurdles are obviously preventing available technologies from being employed, limiting the effect of new R&D investments.

Present research activities in Norway

To ease the process of identifying links between basic research in relevant areas across the fields covered by the Research Council and the more technology-oriented initiatives, a detailed inventory has been made of environment-related programmes and projects supported by the Council. This inventory will also serve as a basis for initiating multidisciplinary initiatives across sectors.

Environmental policies and relevant governmental tools

The aim of this activity, which involves representatives from key ministries, is to identify changes both in priority and handling of the environmental challenges on a national as well as an international level. This coincides well with the Norwegian process of implementing a system of sector responsibility for environment within the government and with the advent of the new EU R&D Framework Programme which includes many environmental aspects.

The listing of established financial tools presently employed and their possible future development will help the Research Council in defining its own tools when compared with the user needs. A number of available evaluations are also being used to describe the possible effect on different user communities.

The view of industry, both problem owners and solvers

This is a major task involving the identification of key sectors in the future industrial development in Norway and an analysis of the environmental challenges involved. Such analysis is, to a large extent, already carried out by the sectors themselves, but needs to be viewed in relation to the societal environmental challenges as well as the expectations for an international framework.

The traditional users of the environmental technology programmes, the problem solvers, are of course challenged to present their list of priorities in the form of expected market opportunities as well as the need for different types of support measures. Identifying areas of common interest with other interest groups and establishing a basis for strategic advice is part of this process.

The view of the research community

Through the close network established between the Research Council and the relatively high number of Universities and Research Institutes active in the field of environment, the latter have been challenged to identify the areas where they would like to see more attention and resources in the future. We thus are trying to extract some of the knowledge gaps that may need long-term financing that industrially-financed projects often do not include.

This also presents an opportunity for more efficient use of the available research funding through the identification of key players in different niches and comparing them to the competing international research community. Such a process is becoming more and more important with the internationalisation of companies and their research base.

The view of the NGOs

To check out the priorities and thinking in the non-commercial, non-technological part of society, a number of active NGOs have been challenged to identify where society should put its research investment in the future. The link to the international headquarters of organisations like the World Wildelife Fund (WWF) and Greenpeace hopefully ties in the priority areas at a global scale when it comes to challenging the Establishment.

The final report

"The proof of the pudding lies in the eating". Hopefully the final report from the project will constitute a broad and sufficient basis for deciding on the shape and size of future initiatives in "Environment and Technology" within the Research Council. Another, more intellectual reward, will be to establish a point of departure for further discussions on the role of technology in meeting future environmental challenges.

Without going more into detail on the different parts of the project, it must be emphasised that the inter-linkage of the views of the interest groups and the subsequent analysis of the responsibilities is the key to the success of the project. Although this has all the characteristics of a national exercise, we view the mechanisms within technology and research as common ground with other industrialised countries along with the environmental challenges that face us all. Consequently I hope this OECD initiative will lead to a further exchange of experiences and practical solutions and results in the near future.

CHARACTERISTICS OF THE HUNGARIAN FORESIGHT PROCESS AND THE SCENARIO APPROACH OF THE "NATURAL AND BUILT ENVIRONMENT" PANEL

by

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Hungarian Technology Foresight Programme (TEP)

Introduction

Our world is characterised by increasingly rapid change in which global trends cannot be stopped at national borders, and new technology is playing a growing role. The world is also becoming more competitive, with national competitiveness depending on technological, organisational and social innovation. As is widely realised firms cannot survive the ever more fierce global competition without investing in emerging technologies and strategic research. These activities, however, are often too risky or too expensive for industry to take sole responsibility for them. Therefore governments must assume at least part of the financial responsibility. This, in turn, requires setting R&D priorities, based on thorough, comprehensive, strategic analysis, as even the richest countries cannot afford to support all research programmes. Technology foresight – a systematic means of assessing that scientific and technological development which could have a strong impact on industrial competitiveness, wealth creation and quality of life – provides an essential tool to this end. Another reason why governments have to take part in foresight is that exploitation of science and technology largely depends on effective networking between business, academia and government. Many governments have realised the importance of foresight activities, and thus this relatively new, and innovative, technology policy tool is spreading across continents.

Hungary launched her foresight programme in 1997. As the country is undergoing fundamental economic and social changes – that is, the transition towards a market economy – major institutions are currently being shaped. The first phase of the transition process is over now. Most firms and banks have been privatised, the most important new political and economic institutions have been re-established, e.g. a parliamentary democracy based on a multi-party system and stock exchange. The so-called transition decline has turned into economic growth in the last few years; therefore, it is high time to think about medium and long-term issues. In other words, it is now possible to devise strategies aimed at improving the quality of life and long-term international competitiveness.

Aims and first steps

Foresight has seemed an adequate tool to bring together business, the science base and government in order to identify and respond to emerging opportunities in markets and technologies. In short, TEP should result in a national innovation strategy based on a comprehensive analysis of:

- World market opportunities (new markets and market niches).
- Trends in technological development.
- Strengths and weaknesses of the Hungarian economy and R&D system.

The above, demanding, aim can only be achieved if researchers, business people and government officials join intellectual forces to assess Hungary's current competitive position and impacts of likely global market and technological trends. Hence their re-aligned and re-invigorated relationships can be regarded as a means to achieve the principal goal. However, the process in which these experts with different backgrounds communicate and share ideas about longer term issues, generate consensus, and co-operate with increased commitment in devising and realising a national strategy, seems to be so crucial that it is an end in itself. In other words, the programme is also aiming at strengthening the formal and informal relationships among scientists and engineers, managers and civil servants, thus spreading the co-operative and strategic thinking.

Hungary is among the six countries about to join the European Union in the "first wave". Accession to the EU is a major challenge since it is likely to shape Hungary's future to a significant extent. It requires a clear and sound vision of Hungary's role and opportunities in the enlarged European socio-economic system. TEP activities and results can contribute to the success of the integration process.

Written TEP results will be comprehensive analyses of strengths and weaknesses, scenarios based on these inquiries and likely global trends, as well as recommendations for public policies regarding how to realise the most desirable scenario. These analyses and information should also assist Hungarian firms in devising and implementing strategies to improve their competitiveness.

TEP is a holistic foresight programme, based on both panel activities (scenarios, SWOT analysis, recommendations, policy proposals, etc.) and a large-scale Delphi survey. The two-year Programme will conclude in 1999. It is being conducted in three stages, namely: pre-foresight (October 1997 – March 1998), main foresight (April 1998 – June 1999) and dissemination and implementation (July – December 1999).

Awareness seminars were held across the country in the pre-foresight stage to promote this new concept among experts and professionals. Participants and organisers of these seminars, i.e., chambers of commerce and scientific associations, were also invited to nominate panel members.

A steering group (SG) of 19 leading industrialists, academics and government officials was set up in October 1997 to oversee the Programme. Following a thorough discussion the SG has defined the following topics for panel discussions:

- Human resources (education, employment).
- Health (life sciences, pharmaceuticals, medical instruments, health care).
- Information technologies, telecommunication, media.

- Natural and built environment.
- Manufacturing and business processes (new materials and production techniques, supplier networks, globalisation ...).
- Agribusiness and food.
- Transport.

Having summarised the reasons to launch TEP, and the results of the pre-foresight stage, some methodological issues are highlighted in the remaining sections.

Strong emphasis on scenarios ("macro" and panel level) institutions and regulation

Given the transition process major institutions are still being shaped in Hungary, as opposed to, for instance, the United Kingdom, where "the lawn is cut and watered for centuries". The fundamental institutions have crystallised in the advanced countries for quite some time, whereas Hungary is still at a crossroads. Moreover, coming back from the Soviet political, military and economic bloc and attempting to join the EU, which is also in the middle of a major transition process, the wider, international institutional context (economic environment) where Hungary tries to find her place, is changing. It is of the utmost importance to analyse this turbulent environment, hence the emphasis on scenario building, both at macro level (socio-economic framework conditions) and at the level of panels (micro, mezzo). Macro scenarios had not been developed in any other country engaged in foresight activities when we designed our programme.[1]

For the same reasons, the Hungarian panels devote a significant part of their interest to institutional development and regulatory issues. This is also reflected in the Hungarian Delphi-statements: quite a few of them deal with these issues, rather than technological ones.

Education and learning as input to competitiveness

There was a *Leisure and Learning* panel in the first British foresight exercise, where learning was mainly understood as a market opportunity, not as a major factor of competitiveness. TEP has opted for the latter approach – for obvious reasons.[2]

Employment as a unique issue

TEP has put together education, learning and employment into one panel under the heading of Human resources. To my knowledge, employment has not been an issue anywhere else. Our decision, however, is self-explanatory in a country in transition.

Broad issues as panel topics

In general, we have brought together various issues treated separately in most other foresight exercises. For example, our *Health* panel encompasses life sciences, related fields of biotechnology, the health care system, pharmaceuticals and medical instruments. Some of these issues are not analysed at all in other foresight exercises, e.g. the health care system, others are treated in separate panels, e.g. life sciences, pharmaceuticals (as part of chemicals). Also, agriculture and food processing belong to a single panel in our case (as opposed to the first British exercise).

Cross-cutting issues

Even so, we have also put strong emphasis on the so-called cross-cutting (cross-panel) issues. We encourage our panels to identify, and adequately deal with these issues (e.g. education and IT in all panels, the various factors affecting our health – life style, medical care, environment, diet: all these issues belong to the different panels, although we have tried to set up panels around broad issues, accession to the EU, etc.). Some panels have already joined forces, i.e. their budget, in the early phase of our programme, and commissioned together a group of experts to analyse issues from different points of view (e.g. healthy diet: *Health – Agribusiness and Food Industry* panels, reasons for allergies: again the two above-mentioned panels).

Given the legacy of the planned economy – that is, strong "departmentalism" – and the inherent isolation of various disciplines, it can be regarded as an achievement in itself.

Organisation

The former socio-economic system has also been influential concerning the organisation and management of TEP. It has been a well-considered, conscious decision from the very beginning not to involve anybody from the OMFB to run the programme (from a professional point of view, i.e. decision on panel topics, issues to be analysed, priority setting, etc.). The role of OMFB has been restricted to providing finance and methodological support. Therefore no OMFB-official sits either on the steering group (SG), or is a member of any panel (the chairman of the steering group was the Head of the OST during the first British foresight programme). Moreover, members of the SG and panels have been appointed as a result of a wide consultation process. All the major decisions are taken by the SG, the panels, or more recently at joint meetings of the SG and panel chairs and secretaries.

Ambiguous ("double") legacy of planning

Centrally set, mandatory plan targets were abolished in 1968 in Hungary, the first time among the centrally planned economies.[3] Yet, the legacy is still rather strong among some experts with two, rather different, consequences, as far as foresight is concerned:

- Some engineers and scientists understand foresight as just another form (tool) of (central) planning, and hence want to devise just one future (vision, scenario, i.e. not different ones), and seeks funding for that target (as a sort of "central development programme [plan]").

- Some professionals also understand foresight – at least at first – as just another form (tool) of (central) planning, and hence reject it immediately.

To sum up, the on-going Hungarian Technology Foresight Programme – its goals, methods and organisation – is shaped to a large extent by the legacy of the former socio-economic systems, their impacts on the national system(s) of innovation, the size of the country and the level of economic development.

Scenario approach of the panel on "protection and development of the natural and built environment"

As a specific panel topic activity, the following scenarios were developed by the panel on natural and built environment, and have been submitted for discussion by the TEP work group.

Objectives

In the course of drafting the possible scenario for the future, the following main principles and criteria were regarded as authoritative from an "environmental" aspect:

- Global principle of sustainability. In this respect the examination of the long-term technological development is deemed important to see what accord is created between the life possibilities of the current generation and the future generations. The basic principle of sustainability is that the short term benefits of the current economic, social activities should not be funded by the costs to the future.

- Regional (EU) and national criterion is to examine how our EU accession can be organised in such a way that harmonisation with the EU and expected economic growth could at the same time promote the improvement of the environmental elements of welfare. The process is related to the environmental protection requirements in the broadest sense since our development should be harmonised with the Fifth Environmental Action Program of the EU whose basic idea is sustainability.

- Regional analyses as well as municipality, entrepreneurial and household levels will play an important role, in accordance with the EU "subsidiarity" principle.

Investigation levels of the technologies

Regarding the technologies the approach is the following:

- Investigation of the methods (technological, economic, social, political) to treat pollution and damage caused by **former** (probably still operating) polluting technologies.

- Moderation of negative impact of **current** and future polluting technologies on the natural and built environment ("end of pipe" procedures, probably change of technology).

- Conditions for **future** development and introduction of environmentally sound technological development and clean technologies, as well as domestic opportunities for the environmental industry.

- In the case of all the above three investigation levels it is necessary to evaluate how technological changes themselves affect the Hungarian **settlement structure**, whether they modify and, if they do, in which direction the life opportunities of the population living in regions of different development levels are heading, and whether they contribute to the moderation of differences related to the area and the type of residential place.

Possible future scenarios

The scenarios relating to the expected state of the Hungarian built and natural environment come from the presumption that Hungary will join the EU in the medium term. Therefore the future of Hungary in the next 30 years (up to 2030) was examined in relation to the EU regarding all the three scenarios.

The consideration in this respect was that if Hungary during this period failed to join the EU for some reason the result would be great uncertainty, with no long-term strategy but only short-term crisis management.

The differences among the three versions are in the extent and pace of the shift towards sustainable development.

Scenario of "sustainable development" (Optimistic version)

The EU, with several new member states, will strengthen its position in relation to the North American and Asian centres. The increased internal market, and the concentrated research and development expenditure will result in above average economic growth. One of its driving forces is the strengthening of the environmental industry, which decreases the environmental load, along with the historically rapid integration of clean technologies into the material basis of the economy. Regarding the use of resources there will be a shift towards human resources; the use of natural capital will decrease. Improving energy efficiency and the decrease of specific use of material is partly the reason, partly the result, of the shift in proportion, which means the products will demand fewer natural resources.

Environmental goals will have an increasing share in the direct objectives of technological developments: progress in environmental areas is emerging among the most successful technologies.

A uniform system of standards covering all countries will spread as the framework condition of economic management and it will regulate the emission values of the individual technologies in detail. The organisational and operational specifications of environmental management will be built into the organisational system of management units at the same level and consistency as in the current accountancy application.

The slow but continuous growth in consumption of the current "developing world" – especially the Asian region – will re-evaluate the raw material stock. The significance of reuse and recycling of raw materials and products will increase in the European region where they are in short supply, and consequently waste minimisation will be highlighted during the development and application of process technologies (including water saving due to vulnerable fresh water reserves).

Regionally the support system of the EU is directed at equalising the development levels of the member states and of the regions within them, and the role of national boundaries is becoming less important. The basic principle of regional support and developments is the modernisation of their resources, so that they will be related to and complementing each other as a network.

This scenario presumes that the European Union implements the goals given in the Fifth Environmental Action Programme ("Towards Sustainability"), and on that basis, is able to advance in the first decade of the next millennium. Between 2010 and 2030 the world economy will then change accordingly and development in harmony with the environment will continue.

Hungary will become a member of the EU by 2005 at the latest. It will implement its National Environmental Programme which is valid until 2002 and which contains the principles of sustainability and, on the basis of an improved programme, Hungary will harmonise with the EU by 2010.

As a member of the EU, the country will have a share of the benefits from the technological developments in the region. Corporate developments will be characterised by the gradual spread of environmentally friendly, clean technologies, and the economy will not be receptive to second-hand, second-class and consequently more polluting technologies.

The duration of the use of the products (life cycle) will increase, which will make repair and maintenance more attractive with positive effects on employment.

The decrease of the environmental load, the increase of environmental safety, the decrease of mobility resulting from more balanced regional development and the spread of work at home or nearby (and consequently the moderation of pollution from transport) will on the whole result in the decline of health damage caused by environmental degradation.

Revaluation of human resources will result in more evenly spread training: the labour force demand of the individual regions will be met by “local” training. As a result of the development of informatics and telecommunication, the scope of job opportunities at home and telecommunication services are expanding. In the wake of the above facts labour mobility will decrease and the harmful impacts of transport on the environment will be moderated.

The residential environment will shift towards so-called dispersed towns (this tendency in Hungary primarily refers to the capital). Relatively big residential structures of medium density, providing space for the natural environment within and around the settlement will become typical. Instead of traditional towns with one centre, there will be towns with several centres and the recreational, servicing, supplying and leisure role will strengthen. This settlement structure will reduce and deconcentrate the environmental load typical of junctions and from transport and in general from the presence of crowds. At the same time the threat of the segregation of social groups due to the geographical proximity of individual settlement centres, or to other (e.g. ethnic) reasons will strengthen.

The importance of public transport will strengthen in order to reduce the pollution from urban transport, to reduce continuous stress and to ensure timesaving mobility. To this end part of the transport routes on the surface (especially at junctions) will pass underground, which means underground construction technologies will advance.

The state of the country in general and the policy on natural and built environment will be similar to that of the current EU cohesion countries (Ireland, Portugal, Spain, Greece), with features resulting from the Eastern Central European situation. With the newly integrated countries, an Eastern Central European Cohesion Zone will be created (Poland, Czech Republic, Hungary, Slovenia and probably Estonia) which, although lagging a little bit behind, will follow the principles of subsidiarity characteristic of the EU average, which is also in line with the global environmental requirements of the world.

Hungary's integration into the EU will promote internal regional integration, and the role of small regions and small communities in solving environmental problems will increase. The “subsidiarity” principle of the EU will exert influence.

In agriculture, production will be shifted towards organic products, organic and environmentally friendly procedures which will reduce the use of pesticides, fertilisers and the resultant soil pollution.

Biodiversity will not deteriorate further. This is due partly to the spread of environmentally sound agricultural solutions, the extension of national parks, environmental areas, more efficient nature conservation in those areas, and partly to improving environmental consciousness. There will be the possibility to resettle and preserve some traditional species.

The shift towards renewable energy sources may become significant, and their share in an optimum case may reach 10%. Use of solar energy, regarded as an alternative today, will continuously increase within the energy supply (this will modify the construction technologies in addition to the application of collectors and photovoltaic cells in solar traps on buildings) and the installation of "earth" houses using traditional heating combined with solar energy and the use of biomass will spread. Construction technologies will be modified. Building materials will not change basically, but the efficiency of insulation technologies will significantly improve.

Taxation of non-renewable resources will gain ground in economic regulation while taxes and employment contributions will decrease. Thus, in addition to the reduction of environmental pollution, the regulation will also decrease unemployment.

The attitude of environmentally conscious management will increase within company corporate management.

The concept of “consumption” will have a different value, the demand for a healthy way of life will increase in the category of quality of life. Then, not only individuals’ interests will have an important role but the “maintenance” of human resources revalued within the production resources will become a strong economic interest. With the spread of waste minimisation technologies and the increase of the non-material consumption elements quality of life (which will reduce the demand for material goods), the environmental load will decrease and the requirements for some technologies prompted by environmental safety (i.e. decrease of the threat of accidents causing environmental and health damage) will simultaneously increase.

A decisive criterion of technological developments and installations is the minimisation of health damage to the population. The external costs of health damage of environmental origin will not come from central funds but will be built into costs at the company level, especially on the basis of the polluter pays principle.

The immaterial value scale will become dominant in family and school education, quality of life will have priority over pursuing material goods. Raising environmental awareness will become a cornerstone of the education system from the lowest level (nurseries) to higher education, including further training at different levels. The educational system will deal with the environmental impacts of given areas as part of certain subject matters, professions and fields. In addition, it will regard and apply environmentally sound thinking as the basic element of education relating to the way of life.

“Business as usual” scenario

Slow economic growth in the European Union: the position of the region in the world economy will slightly deteriorate and the Union will not implement the programme of sustainable development. The traditional growth-orientated development of the world economy will significantly delay the environmentally sound transformation of the profit-orientated relations of nature-economy.

The Union funds will grow slowly due to the resistance of the donor countries and the demand of the formerly integrated cohesion countries will be strong to preserve the support resources. The Central Eastern European integration will proceed slowly.

Hungary will join the European Union after 2005 but the practice of "sustainable growth" will devaluate the principles of "sustainable development" and will significantly delay its realisation.

The current production-consumption structure will survive. The proportion of technical development will remain low, the economy will be determined by "lease" work. (The current level of R&D and the role of Hungarian research development centres will keep decreasing.) The financially most successful, efficient technologies will not be aimed directly at the protection of the environment but, as an additional benefit from their application, the environmental load will decrease.

EU support will go for road transport within infrastructure development and more environmentally friendly transport solutions will relatively decrease in importance. Accelerated motorway construction will strengthen the transit nature of the country. The above endeavour is in accordance with the Hungarian development of motor car production.

Differences between the trans-Danubian and Eastern regions regarding regional development will not decrease.

Regarding technological development, the basically Hungarian owned small and medium sectors will lag behind the advanced level of large international companies. In Hungary the multinational companies with high capital level use first class technologies of an environmentally friendly nature. On the other hand, small and medium companies – due to relative capital shortage – take over second class procedures, which are more environmentally detrimental. The spread of the latter, however, is not typical. Environmental regulation will remain relatively soft, due to the strong resistance of the majority of both the population and businesses. Within environmental solutions, subsequent environmental protection through low efficiency end-of-pipe measures will dominate.

Primarily large companies and their suppliers use organisational and operational forms according to the Environmental Management System, which is based on the continuous development of the ISO 14001 standard. The number of certified companies working on the basis of EMS will be a few thousand in Hungary.

The environmental industrial products and services will be imported, with a negative effect on the international balance of payment.

The environmental health situation will stagnate, and in some fields will deteriorate, especially in big crowded cities. Monitoring systems to observe the impacts of technologies resulting in health damage of environmental origin will be established. During company installations and expansions, environmental impact assessment will certify the installations on the basis of standards tighter than the current environmental health standards, the contacts between environmental and health authorities will be continuous. At the same time strategic impact assessments will be hardly used for developments.

A part of the valuable natural areas will be lost because of infrastructure development and green field industrial investments.

Energy efficiency will improve slowly, the interest in increasing energy production is much greater than in increasing energy efficiency (basic power stations fuelled by lignite, perhaps a new nuclear power station).

Because of the poor enforcement of the subsidiary principle, the role of local governments in reducing environmental damage will strengthen only slightly. The local governments will organisationally expand and staff trained for environmental tasks will be employed. Local governments will have greater control over duties and fees collected for environmental purposes. In the case of the remaining centralised funds, not only will a *per capita* distribution system exist, but the nature and extent of the pollution to be cleaned up will also have significant impact.

The environmental tasks of the Hungarian local governments will be concentrated on two areas: waste disposal and sewage purification.

Knowledge relating to environmental protection as a separate subject will have a broadening role in the educational system, especially at the secondary level. This profile of higher education is expanding especially in the fields of waste treatment technologies and environmental management. Public thinking is primarily influenced by environmental information in the media, given separately or built in to other types of information. Environmental awareness of the public however changes slowly because of other impacts working against the environment.

It is increasingly difficult for the country to meet the requirements stipulated by international environmental conventions.

“Delayed accession” scenario (Pessimistic version)

The European Union will fall into the background among the major world economic centres. Traditional market solutions will dominate in the world economy. Global and regional conflicts will sharpen, and permanent crisis management will absorb significant resources. Subsequent (end-of-pipe) instruments both environmentally and economically of low efficiency, will become typical in environmental protection. Only multinational companies – primarily to ensure their "green" image – apply the slowly changing standards of environmental management. The standards in the world economic regions differ in relation to the stringency of the stipulations.

Because of the sharpening world economic contradictions the development of the EU will slow down, and accession will be postponed to 2010 or later. In Hungary environmental protection will diminish and will be subordinated to economic growth of low efficiency. The driving force of technological developments will be profit maximisation in the short term. The reduction of the load on environmental elements with its long-term, indirect benefits will be left out of the group of the economically most successful technologies. Rapid developments responding to existing deterioration of the environment will have priority.

The threat of using polluting technologies in industrial production as a result of economic constraints will grow, the enforcement of environmental criteria will be weak. The number of companies certified on the basis of environmental standards will stagnate at a few hundred.

Hungary will be on the periphery within the Union, which will determine the level of technologies used, i.e. typically second class with all the associated environmental disadvantages. The major countries of the European region will see the Eastern end as the domain of the relatively most polluting technologies: development funds will be aimed at the take-over of these technologies.

Agricultural production will continue with environmentally polluting methods on fragmented areas, with the ownership structure transformed as a result of the lack of knowledge and capital. Negative effects (primarily soil pollution) of previous polluting agricultural technologies will not be eliminated.

Processes resulting from the transit character of the country will strengthen in transport, road development will grow while the role of railway and public transport will decrease. The vehicle fleet will age and the technical state will further deteriorate.

As a result of short-term developments with direct benefit, the second class polluting technologies coming to Hungary and the limited budget opportunities, monitoring of health damage of environmental origin and the treatment of damage on a social level will not be highlighted. Prevention will be restricted and limited to spectacular emergencies (e.g. chemical accidents) which are easily perceptible by the public. The share and typical impact of health damage resulting from environmental pollution will not be clarified.

The development funds of local governments used for environmental protection will be restricted. There is no requirement to employ experts who can manage environmental issues on the merit, as the regional environmental authorities will control the remediation processes. Funds earmarked for environmental purposes will be centralised, the distribution system *per capita* will be employed or the funds will be used to eliminate emerging damage.

The importance of the medium strata in the society will not change, the development of the civil society will be slow, sensitivity to non-material values and environmental awareness will be at a low level. The media will only moderately influence environmental thinking, since it has a subordinated role in the social scale of values, and since it has no value for advertisement. Education will primarily concentrate on knowledge necessary for remediation: training at the secondary and higher education levels will be relatively limited. An environmentally friendly way of life will be in the periphery in education, the attitude based on the utility of people measurable in financial terms will prepare the new generation for careers which entail the possession of material goods and are deemed successful by the public.

The peripheral nature of the Central Eastern European countries will remain. The regional differences and conflicts within the countries will grow. Because of the lack of adequate resources, the Eastern territories will not catch up fast, and developments will be concentrated on areas with existing infrastructure and better qualified labour.

Biodiversity will drastically deteriorate due to the decrease of nature conservation areas, moderation of financial means to preserve them, utilisation of many chemicals to extend agricultural territory, and narrowing natural living space.

NOTES

1. Scenario-building has been an important innovation in the British foresight exercise, but only applied at panel level. More recently, macro scenarios have been developed in the South African foresight programme.

2. During the second British foresight exercise, to be launched in April 1999, more emphasis would be given to learning as an input to competitiveness.

3. Central planning was not abolished until 1989.

RESOURCE-EFFICIENT TECHNOLOGIES – RESULTS AND METHODOLOGICAL ASPECTS OF THE GERMAN DELPHI '98 SURVEY

by

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The Delphi technology foresight

Growing competition on the world markets and increasing technological change are forcing economies and organisations to concentrate their research activities on selected areas. Identifying emerging technologies and new applications is one of the key questions in research policy. One of the prominent foresight methods is the *Delphi technique*. The Delphi method is especially useful for long-range forecasting (20-30 years) where expert opinions are the only source of information available (Martino 1983).

In Germany, two large Delphi technology foresight exercises have been carried out up to now. In 1993, the results of a first study were published. In view of the long-standing experience in Japan, where the Science and Technology Agency (STA) has used this method every five years since 1971 for its technology foresight, the German Delphi investigation deliberately followed the Japanese guidelines (aims, topics, character and method) and duplicated the fifth Japanese Delphi survey of 1991. The results of the Japanese survey are presented in NISTEP (1992). has published The German survey results were published by the German Federal Ministry for Research and Technology (BMFT 1993) which commissioned the underlying research project to ISI (Fraunhofer Institute for Systems and Innovation Research). One aim of this approach was to compare the Japanese and the German answers in order to analyse possible differences and to understand the cultural influences on technology assessment (see Cuhls and Kuwahara 1994).

The second German Delphi technology foresight report prepared by ISI was published in 1998 (ISI 1998). For this survey, 12 technological areas were defined, containing topics for which expectations of realisation of defined stages of development (exploration [also called elucidation] => industrial development => first application => general application) were requested from participants in the survey (panellists).

For each of the 12 technological areas one questionnaire was developed. The questionnaires were identically structured and covered variables like importance, time of realisation, national levels of research and development (R&D) activities, important measures to be taken for realisation and possible follow-on problems to assess each topic. The variables were defined as follows:

- *Importance:* Importance of the topic for the enlargement of human knowledge, economic development, social development, the solution of ecological problems, work and employment.

- *Time of realisation: Estimation* of the period of realisation: until 2000, 2001-2005, 2006-2010, 2011-2015, 2016-2020, 2021-2025, after 2025, never realisable.

- *National R&D levels: Which* nation is leading in regard to research and development (R&D): the United States, Japan, Germany, another EU Member State, or another country.

- *Important measures for realisation: Improvement* of the qualification of R&D personnel, exchange of personnel and know-how between science and industry, international co-operation, improvement of R&D infrastructure, support (of R&D) by government, foundations etc., change of regulation.

- *Possible follow-on problems*: Will the technical developments lead to problems in the fields of environment, safety, or in the social/cultural/societal situation?

In addition, each panellist was asked to assess his or her individual degree of expertise as high, medium, low or none (for each specific question or "thesis").

The final part of the questionnaire (in round 1 of the Delphi survey) contained "megatrends" concerning the world's economic, societal, political, and social conditions during the coming decades. These were brought to the table for discussion in order to examine which images of the future guide the experts and whether they expect these to exert significant influence on the development of science and technology.

Results with regard to environmental issues

With its 12 technological areas, from large scale experiments in the natural sciences to topics relating to a service society (cf. Table 1) the German Delphi '98 survey aims at covering the complete spectrum of issues relevant for the long-term development of (hard and soft) technologies. The topics either picture scientific/technical disciplines ("geosciences") or application fields ("transport").

For the field of environmental issues there are different approaches for analysis. The analysis may concentrate on the results of the specified thematic field "Environment and Nature" or employ a transversal analysis of all relevant topics for environmental issues contained in the technological areas of the Delphi survey. These approaches were both presented in a lecture at the 1996 conference *"Quel environnement pour le XXIème siècle? Maîtrise du long terme et démocratie"* in Fontevraud (Kuntze 1997).

For the present paper, a different focus has been chosen. As a first step, a short analysis of the questions on "environment and nature" will be presented. The main part of the paper, however, will concentrate on a transversal analysis of the consideration of resource-efficient technologies, cutting across all technological areas of the German Delphi '98 survey.

Table 1: Thematic areas Delphi '98

Delphi '98 thematic areas	Number of theses in Delphi '98	Identical theses in 6th Delphi Japan ('97)	Identical theses in Delphi '93
Information & Communication (INFO)	111	68	16
Service & Consumption (SERV)	78	21	6
Management & Production (PROD)	71	14	7
Chemistry & Materials (CHEM)	104	33	24
Health & Life Processes (BIOM)	104	36	7
Agriculture & Nutrition (AGRO)	101	20	7
Environment & Nature (ENV-NA)	76	15	2
Energy & Resources (ENER)	114	32	14
Construction & Dwelling (CONSTR)	75	32	9
Mobility & Transport (MOBI)	107	18	5
Space (SPACE)	78	24	9
Large Science Experiments (L-EX)	51	10	7
Total	**1.070**	**323**	**113**

Source: Author.

Thematic field environment and nature

This technological field consists of 76 innovations (theses) in the following areas:

- Protection of the atmosphere (13 theses).
- Biotope protection and forestry (5 theses).
- Urban environment (11 theses).
- Waste management (5 theses).
- Soil protection (8 theses).
- Water supply/waste water (17 theses).
- Protection of the marine environment (4 theses).
- Monitoring/environmental information (13 theses).

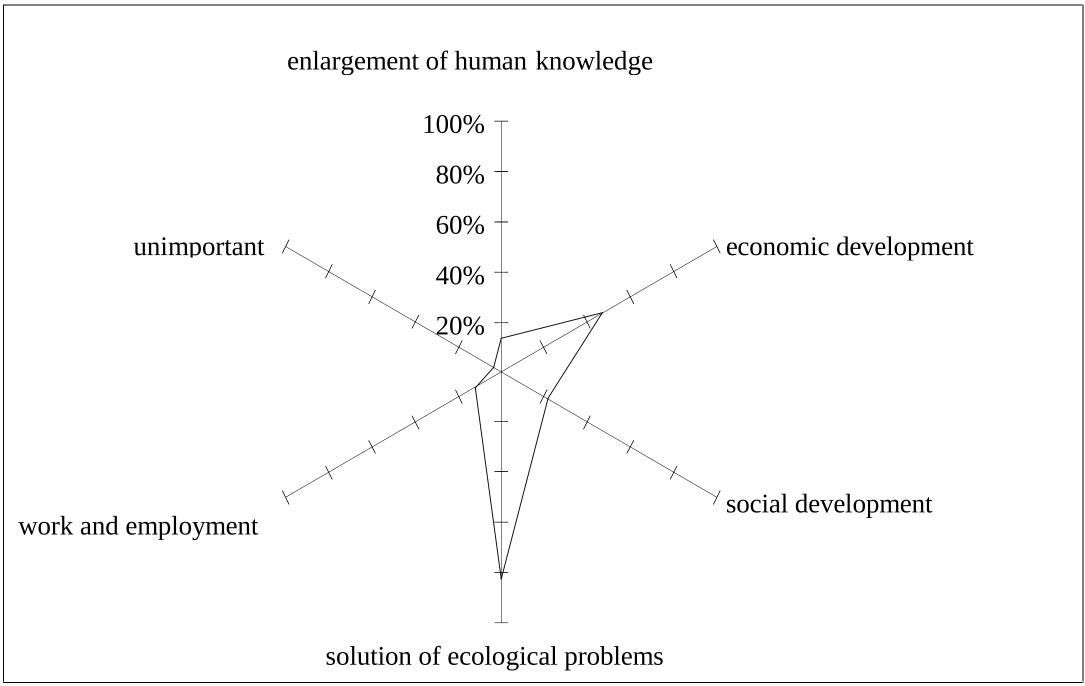
The importance of the thematic field "environment and nature"

Each of the theses treats a contribution to the solution of a specific problem. Their importance for different aspects of society is displayed in Figure 1.

While for all thematic fields the panellists judge their contribution for economic development as the most important of all the aspects considered, with the contribution for the solution of ecological problems following second at a considerable distance, in the thematic field of "environment and nature" this order is reversed. This result was to be expected. What is remarkable, though, is the high level of importance attributed to this thematic field for economic development, which almost half of the panellists expressed. One reason for this attribution can surely be found in the growing integration of environmental aspects in production and process technologies, thus integrally combining it with know-how and value-added shares and their economic contribution.

Interestingly, there is no difference between panellists from science compared to those from industry with regard to the importance of the solution of ecological problems and of economic development. Obviously, none of the panellists regards environment as a barrier to economic development.

Figure 1. The importance of the thematic field "environment and nature" for different aspects of society



Source: Author.

On the level of the single theses the following were judged as the most important by the panellists:

- **Importance for the enlargement of human knowledge**: *atmospheric processes and climate models* more important than *earthquake prediction* which was rated more important than other theses concerning climatic change.

- **Importance for economic development**: decentrally-applicable technologies for drinking water treatment, biotechnological development of drought and salt resistant high yield plants, seafarms, need for controlled fertilisation, remote exploration systems for the prediction of floods.

- **Importance for social development**: new settlement structures for the reduction of traffic-borne environmental burdens, limitation of land use, 10% of the surface of Germany under nature protection, and methods for the prediction of floods.

- **Importance for the solution of ecological problems**: remote control of the oceans against immersion of harmful substances, reduction of the emission of persistent harmful substances to an ecologically sustainable level, finishing the large-scale clearing of rain forests, substitution of CFC and halogens, and biotechnological and physical processes for the *in situ* sanitation of groundwater damages.

- **Importance for work and employment**: ecological farming on 40% of German territory, recultivation of damaged tropical forests, technologies for the recultivation of deserts, for Nox-reduced motor vehicles and soil preserving farming methods and processes.

While these results in general are very plausible, it is interesting to note that in each category of importance theses of a primarily local orientation as well as of a global orientation are to be found. Therefore one cannot speak of a crowding out of global problems.

When will the theses become reality?

Concerning the expected realisation periods of the individual theses there are no significant differences between the thematic field "environment and nature" compared to the average of all thematic fields. The median of realisation is the year 2012.

There are interesting differences, though, in the variance for the time of realisation of the theses in the different areas of the thematic field "environment and nature". For theses concerning public supply and disposal, hence rather "local" problems which lie in the range of everybody's immediate experience, the expected realisation period is on average substantially earlier than for such theses which tackle "global" questions that lie outside the daily, immediate range of experience.

The medians for the expected year of realisation in the different thematic areas of "environment and nature" are as follows:

- Waste management 2009 ± 3.
- Water supply/waste water 2010 ± 4.
- Protection of the atmosphere2013 ± 4.
- Biotope protection and forestry 2013 ± 4.
- Monitoring/environmental information 2013 ± 4.
- Protection of the marine environment 2014 ± 4.
- Soil protection 2014 ± 5.
- Urban environment 2016 ± 5.

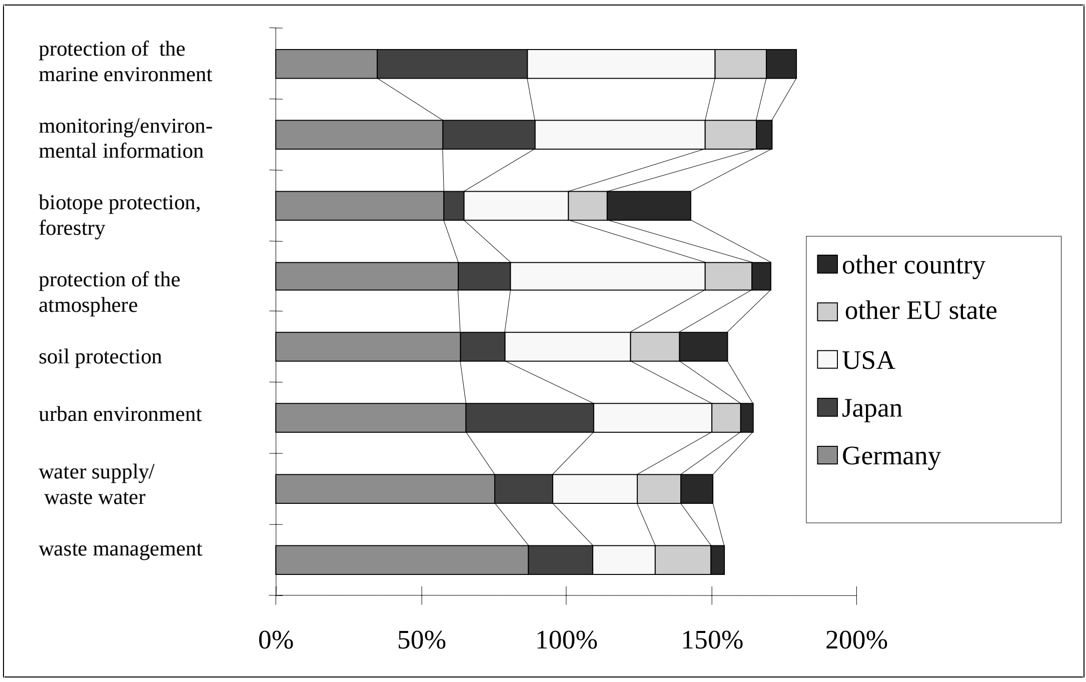
The two thematic areas "waste management" and "water supply/waste water" are attributed the greatest importance for economic development as well as being judged an area in which Germany is leading in R&D. This points to the chances lying in a deliberate combination of ecological and economic aspects to expand German competitive advantages on the world markets for the technologies contained in this field.

What is the German position in environmental research and development?

Concerning the position of environmental R&D, a majority of panellists (65%) judge Germany to be leading, followed by the United States (45%), Japan (25%) and other EU Member States (15%).

A more differentiated picture is obtained when analysing the position in R&D in the different thematic areas of "environment and nature" (Figure 2). It shows that the leading position for Germany is attributed to the areas "biotope protection and forestry", "urban environment", "waste management", "soil protection" and "water supply/waste water". In contrast, the leading position is attributed to the United States in the areas of "protection of the atmosphere", "protection of the marine environment" and "monitoring/environmental information". Japan is judged to be ahead of Germany in R&D in the area of "protection of the marine environment" which is not astonishing in view of the insular situation of Japan.

Figure 2. German position in environmental R&D in international comparison ("which country is leading in R&D?")



Source: Author.

Which measures are to be taken?

What is the role of technology policy measures in this context? Like all other thematic fields, the panellists judge "international co-operation" as the most important measure for the realisation of the theses in the area of "environment and nature". In this thematic field, though, the second important measure (in the same order of magnitude as "international co-operation") is seen in "changes in regulation" whereas in other thematic fields the second most important measure is improvement of the R&D infrastructure. This points to the fact that in the field of environment and nature there exists a need for action which is also considered as important for the improvement of the environmental situation.

These results can be differentiated according to the ranking of the theses with regard to their importance for realisation. Concerning international co-operation the majority of panellists consider the themes of "protection of the atmosphere", "protection of the marine environment" and "monitoring/environmental information" to be of highest relevance. In contrast, for the topics "urban environment", "waste management" and "water supply/waste water" a clear majority considers changes in regulation to be the most important measure. Again this shows that for topics concerning rather "local" environmental problems a change in regulation is preferred to other measures to support realisation, whereas for topics of a rather global aspect international co-operation is judged to be the preferred measure for realisation. Especially significant is the high percentage of the panellists who judge change of regulation ("re-regulation") to be an important measure in the field of "waste management". Quite obviously, there exist important unused margins for action.

Cutting across all thematic fields: results for the transversal issue of resource-efficient technologies

The short glance at the thematic field "environment & nature" presented in the preceding section can only touch upon the rich material in the Delphi survey.

There are clearly different approaches to the analysis of the material. One such approach would be the analysis of the theses covering aspects of the concept of "sustainable development". Although the operationalisation of sustainable development is far from a consensus, at least some of its elements can be named. Among them, respecting the earth's carrying capacity, the existence of long incubation times for specific environmental problems and the irreversibility of certain processes pose a severe challenge to the application of technologies. This puts efficiency in the processing of natural resources (water, energy, materials) at the forefront of efforts. In fact, the understanding that waste and emissions are poorly used production inputs gains ground. The much disputed reconciliation of ecology and economy can therefore only be realised if and as far as resource efficient technologies are applied. In many cases, because of using less resources, this also means less costs.

What do we mean by resource efficient technologies?

First of all, the definition of resource efficient *technologies* does not solely comprise hardware technologies but also, organisational solutions and alternative concepts of serving human needs, for example. This means that all approaches to use inputs to the highest maximum possibility, avoiding waste and/or putting production residues into secondary raw material which others may use as production inputs.

For the purpose of this paper we have defined *resources* as material resources (materials, energy, water), not including, e.g., land use, health, prospection methods for new resources, or the qualification of the work force. For a different analysis these resources should well be considered, also.

Definition of resource-efficient technologies (RET)

- **Technologies**
  including organisational solutions, alternative concepts
- **Resources**
  material resources, without: land consumption, health, measurement/control technologies, resource prospection
- **Efficiency**
  savings, not solely following economic criteria, including substitution

⇨ 183 theses (of a total of 1 070) from 10 out of 12 thematic fields

The term *efficiency* is being used here as signifying saving material resources (including substitution of non-renewable materials), not solely evaluated with economic criteria. Economic evaluation is extremely difficult and may be misleading because of the fact that significant parts of existing costs are not being incorporated into market prices ("social costs") though they will appear elsewhere and at some point for market participants. To avoid discussion about social costs on the one hand, and to include the consideration of technologies which may not be economically "efficient" in the current price structure, on the other hand, we have chosen to use a wide definition of efficiency for the purpose of this analysis.

Which information does the Delphi '98 survey present for this topic?

Certainly, in the thematic field environment and nature, with its 76 theses, relevant theses for this topic can be found. Obviously, considering sub-fields like:

- Protection of the atmosphere: 13 theses
- Biotop protection and forestry: 5 theses
- Monitoring and environmental information: 13 theses

it soon becomes clear that the field environment and nature only contains a fraction of the topic "resource efficient technologies". Instead, quite a number of theses concerning the future development of science and technology ought to be found in different thematic fields of the Delphi survey such as, "chemistry and materials" or "management and production". In fact, of the total 1 070 theses of the Delphi survey we have identified 183 (17%) dealing with "resource efficient technologies" according to our definition. This procedure, too, must be discussed methodologically as to its impact on the results, a first outline of such a discussion is presented later in this paper.

These 183 relevant questions for resource efficient technologies from all technological subfields will be the basis of further analysis in this section. Roughly, they may be categorised into technological topics as in Table 2. These are more highly differentiated and therefore offer a better possibility for thematic analyses.

Table 2 also shows the origin of the topics from the different thematic fields. This first of all illustrates that only 20 of the 183 topics (i.e. 11%) of resource efficient technologies originate from the thematic field of environment and nature. That field is not even the relatively most important contributor to resource efficient technologies, as only 26% of its theses belong to these topics. Relatively (and absolutely) more important are the thematic fields "energy and resources" and "chemistry and materials" which contribute 28% and 34%, respectively.

With the exception of "space" and "large scale science experiments", all thematic fields contribute with theses to the technological topics of resource efficient technologies. And although there are focal technologies in the thematic fields, they contribute to different technological topics. The example of the thematic field "information and communication" shows this very clearly: with two-thirds (9 out of 13 theses) of the thematic field contributing to the information/communication group of resource efficient technologies there exists a very strong focal point, but information and communication theses also contribute to the technological topics of super-conductivity and concepts of production/utilisation of products. This point is made here to make it very clear that the richness of the Delphi material would only be touched upon if the analysis were restricted to the thematic fields.

Table 2: Composition of the transversal topics of resource-efficient technologies

Technology	**Count**	Chemistry & Materials	Energy & Resources	Environment & Nature	Agriculture & Nutrition	Construction & Dwelling	Management & Production	Services & Consum-ption	Information & Communi-cation	Mobility & Transport	Health & Life Processes
Facility technology	15	1	3			8		3			
Water supply/waste water	16			11	1	4					
Energy supply/ energy technology	17	4	8	3		2					
Solar cells	5	3	2								
Superconductivity	4	2					1		1		
Vehicles technology	14	3	3							8	
Concepts of mobility	7							3	1	3	
Concepts of production/ utilisation of products	19		7		2		4	3	2	1	
Manufacturing technology/ process technology	20	7	4	1	2		6				
Catalysts	4	3					1				
Renewable resources	13	2	2		7						2
Materials	11	9					1				1
Recycling	5		2	1		2					
Information/ communication technology	13	1			2		1		9		
Agricultural technology	18		1	4	12			1			
Others	2					1		1			
Sum of counts	**183**	**35**	**32**	**20**	**26**	**17**	**14**	**14**	**13**	**12**	**3**
in% of the thematic field	**17,1**	**33,7**	**28,1**	**26,3**	**25,7**	**22,7**	**19,7**	**17,9**	**11,7**	**11,2**	**2,9**

Source: Author.

The most important theses for economic development of resource efficient technologies

Considering the totality of the 183 theses, a ranking of the different variables (importance, realisation time, measures for realisation etc.) is the first analytical step. To condense the material, Table 3 shows the "top ten" theses ranked highest by the experts with regard to their importance for economic development. To show a list of only ten questions was an arbitrary decision because the following ten or more questions might also have a comparably high ranking. For the top ten of importance for economic development in fact, a larger number of topics, 13 in this case, are ranked equally. Within the order of "highest ranking" we have maintained the ranking according to ordering numbers (technological field/number of the topic) which is absolutely arbitrary: results of this ranking method may, therefore, not be interpreted. Furthermore, it should be borne in mind that the top list represents collective assessments and may not include disputed topics that are highly esteemed by selected expert groups only.

Considering these 13 theses of resource efficient technologies ranked highest for their importance for economic development (Table 3), it can be stated that there is an almost unanimous rating: 96 – 99% of the experts rate these 13 topics highest whereas this ratio drops to 13% for the last of the 183 theses considered here. This remarkable consensus among the experts is confirmed when taking into account that hardly any experts (0-7%) have doubts as to the possibility of realisation of the different topics.

Of the 16 technological areas of resource efficient technologies which we have formed for this analysis (c.f. Table 2), six are represented among the "top 13" which indicates that there are economic chances throughout all the technological areas.

Concerning the expected *ecological relief*, the theses ranked highest for their economic importance contribute rather below average. While this does not prove that the much disputed reconciliation of ecological concerns with economic prosperity should not be possible, it points to a necessary differentiation of opportunities and problems connected with the individual topics.

The exchange of personnel or know-how between science and industry and international co-operation are judged to be *important measures for realisation*.

Table 3. The 13 topics of resource efficient technologies ranked most important with regard to economic development

			Degree of expertise %			Importance for ... (%)						Year of realisation				Highest R&D level (%)					Important measures for realisation (%)						
Thematic field	Theses	**number of answers**	high	medium	low	enlargement of human knowledge	economic development	social development	solution of ecological problems	work and employment	unimportant	lower quarter (Q1)	median	upper quarter (Q2)	never realisable (in %)	USA	Japan	Germany	other EU member state	other country	improved qualific. of R&D personnel	exchange science/industry	international co-operation	improvement of R&D-infrastructure	R&D support by govt., foundations et	change of regulation	others
INFO	Components able to integrate sensors, controllers, and actuators have practical applications in microtechnology.	113	11	32	58	8	99	25	18	41	0	2002	2005	2008	0	50	53	80	1	1	21	35	62	76	32	1	0
CHEM	New catalytic systems will be developed that make selective CH-activation in methane a reality, so that methanol can be produced directly from methane.	105	22	37	41	30	99	2	44	12	1	2008	2011	2015	2	74	32	84	12	1	17	26	51	49	69	3	0
CHEM	In technical syntheses, the reaction and material separation steps will be process-integrated in a single device, for example, by means of reactive distillation or in a membrane reactor.	112	17	39	44	9	98	4	55	18	2	2006	2011	2016	5	42	31	91	12	5	14	57	32	67	54	1	1
CHEM	A non-destructive testing technique (e.g. "health monitoring") will be developed which will permit the condition or performance reserves of metallic materials to be examined, from the results of which the probable, residual operating life can be determined.	100	11	33	56	27	98	5	11	11	0	2005	2009	2013	0	86	28	63	10	1	10	29	49	34	67	2	0
AGRO	Cell cultures in large-scale bioreactors will find widespread employment for the manufacture of highly pure substances die (e.g., pharmaceuticals, high purity chemicals, proteins).	101	3	25	72	14	97	10	13	13	0	2005	2008	2011	1	89	62	42	5	4	11	40	73	33	35	12	1
ENER	Solution mining will be used in practice with which deep-earth metal ore reserves like copper pyrite or sulfid minerals with lead and zink can be solved and pumped off from the surface.	104	7	24	69	7	97	3	19	20	3	2011	2016	2020	5	92	18	26	5	14	6	24	86	23	18	6	0
CONST	The technical provisions for facility management systems are already realised at the phase of new construction.	65	22	40	38	6	97	13	30	39	0	2002	2004	2007	0	85	35	61	11	2	67	38	7	45	21	7	9
CHEM	A new process will be developed that allows tailor-made polycondensation materials to be produced.	127	7	33	60	18	97	3	11	30	1	2004	2007	2010	0	67	37	77	6	2	15	39	39	57	39	3	1
PROD	Intelligent materials (e.g. memory alloys, piezo-electric ceramics, magneto-active materials, magneto-electric adhesive fluids etc.) capable of adapting to external influences are applied to a greater extent to expand the efficiency of machines.	121	3	28	69	15	97	5	18	35	0	2005	2008	2011	0	75	56	35	3	4	12	41	52	51	19	2	3
PROD	Materials are industrially applied which are superconductive at room temperature.	121	3	22	74	22	96	8	37	26	0	2009	2014	2019	7	80	35	44	4	5	15	24	68	52	28	3	1
PROD	High value products are produced under continuous optimised process control so that costly final quality controls are dropped.	152	26	45	28	4	96	1	14	53	0	2002	2005	2008	1	30	93	47	5	1	66	30	27	38	16	9	3

Source: Author.

With topics ranked high above average for the *science/industry exchange* like "in technical syntheses, the reaction and material separation steps will be process-integrated in a single device, for example, by means of reactive distillation or in a membrane reactor", "intelligent materials (e.g. memory alloys, piezo-electric ceramics, magneto-active materials, magneto-electric adhesive fluids etc.) capable of adapting to external influences are applied to a greater extent to expand the efficiency of machines" and "cell cultures in large-scale bioreactors will find widespread employment for the manufacture of highly pure substances (e.g. pharmaceuticals, high purity chemicals, proteins)" these results support the finding of a growing science base of economically promising modern industries (Grupp/Schmoch 1992).

Furthermore, a larger-than-average share of the experts think *international co-operation* is an important measure for realisation. Topics such as "solution mining will be used in practice, with which deep-earth metal ore reserves like copper pyrite or sulfid minerals with lead and zinc can be solved and pumped off from the surface", "cell cultures in large-scale bioreactors will find widespread employment for the manufacture of highly pure substances (e.g. pharmaceuticals, high purity chemicals, proteins) and "by utilising the development potential above the chip level (chip-on-board technology, multi-chip modules, 3-D chips, and wafer scale integration), jumps in packing density of two orders of magnitude will be achieved" are examples for the largest shares. These often correspond with ratings which suggest that Germany is lagging behind in R&D in the specific topic. Obviously, panellists think international co-operation is one possible measure to catch up with commercialisation.

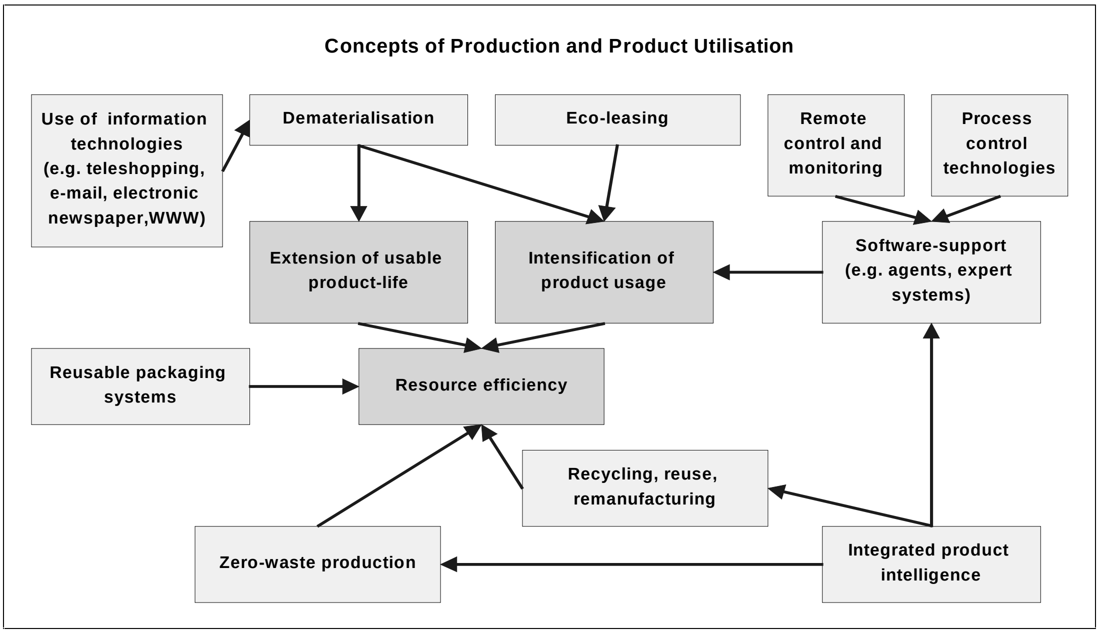
In contrast, *changes in regulation* are not assessed as being of particular importance. Rather, the 13 economically most important theses are rated below average concerning a necessity for a change in regulation. These findings deliver a strong point for the view that (environmental) regulation in practice is regarded as much less of a barrier to innovation and economic performance than is often put forward by rigid market economists and industrial lobbyists. Corresponding empirical results have also been presented in a number of studies (c.f. e.g. Walz/Kuntze 1999).

A scenario of theses of concepts of production and product utilisation

As interesting as these results are, the need is still felt to put the single theses into wider contexts. Especially on the level of strategic decision making for individual companies, there is a need for a different arrangement of the findings so that a picture of thematically neighbouring theses may be formed. We have therefore tried to group together different topics into thematically coherent groups. These groups may be structured in a form resembling a scenario.

One such scenario concerning concepts of production and product utilisation is displayed in Figure 3. The arrows in Figure 3 show thematic relations between the different groups of topics. The panellists' expectations as to time, probability, importance, R&D level and supporting measures of the theses forming this scenario are presented in Table 4.

Figure 3. Resource efficient technologies contributing to sustainable development: the Delphi '98 scenario of concepts of production and product utilisation



Source: Author.

Discussing such concepts illustrates that beyond products and techniques there exist considerations which more radically think about the "what" and "why" of products and production. In fact what a client needs often is not the possession of a certain product (e.g. an automobile), but rather he wishes his mobility needs to be served. Making this difference and utilising a systemic view often leads to quite new perspectives on the life cycle of products, to the production, distribution, utilisation, recovery, re-use and recycling (c.f. Stahel 1998). Taking on this perspective also leads to different perceptions of threats and opportunities associated with industrial activities under the paradigm of resource efficient technologies for sustainable development (c.f. Meyer-Krahmer 1998) as well as the role of a public research and technology policy in this context (Kuntze 1998).

For a very short survey of the topics contained in this scenario we will concentrate on the expectations of realisation time of the three main concepts of production and product utilisation: the extension of product lives, the intensification of the utilisation of products and the tackling of recycling, re-use and re-manufacturing.

Table 4. Concepts of production and product utilisation

Thematic field	Theses	number of answers	Degree of expertise %: high	medium	low	Importance for ... (%): enlargement of human knowledge	economic development	social development	solution of ecological problems	work and employment	unimportant	Year of realisation: lower quarter (Q1)	median	upper quarter (Q2)	never realisable (in %)	Highest R&D level (%): USA	Japan	Germany	other EU member state	other country	Important measures for realisation (%): improved qualific. of R&D personnel	exchange science/industry	international co-operation	improvement of R&D-infrastructure	R&D support by govt., foundations etc	change of regulation	others
PROD	The tendency to shorter product life cycles will have reversed to favour prolongation and intensification of product utilisation.	157	15	59	27	4	71	24	78	46	2	2005	2008	2012	11	18	25	89	8	1	30	19	39	24	15	59	4
PROD	Manufacturers of durable consumer goods will be legally obligated to take back their goods at the end of their service lives. This will result in a recycling system integrating planning, production, collection and recycling or re-use in a practically completely closed material cycle.	163	15	60	25	6	65	31	93	51	1	2002	2005	2009	2	6	4	99	11	0	22	16	32	12	24	82	1
PROD	Inter-firm coupled production will be realised, using scrap from one company as materials input to another ("zero waste production").	154	10	50	40	5	65	17	94	31	3	2010	2013	2017	24	17	22	88	9	2	23	22	47	22	26	65	4
PROD	Re-manufacturing and re-use will replace the production of new products and reach 50% of the turnover.	159	10	57	33	5	72	21	88	36	0	2009	2013	2019	11	8	13	94	11	5	26	19	39	25	26	74	4
AGRO	Because of electronic home shopping, up to 50% of all food items will reach the consumer without having passed through the hands of traditional merchants.	75	1	17	81	1	86	52	6	42	8	2009	2013	2016	25	98	20	11	9	3	8	23	36	10	15	52	8
AGRO	With at at least 50% of packed food items reusable packaging based on deposit-refund systems will be used.	102	5	31	64	0	55	17	83	17	4	2004	2007	2010	27	8	5	97	15	3	17	3	10	2	16	85	6
ENER	Integrated product intelligence (IT systems) will find widespread use, detailing how, at the end of its service life, a product can be disassembled and its component parts can be gathered and resources recovered from them.	144	6	30	65	4	56	22	97	34	0	2007	2010	2014	1	11	25	98	8	0	13	14	27	16	28	77	3
ENER	Techniques will be widespread in industrial states which allow almost 100% recycling of construction demolition material like concrete, glass, window frames, asphalt and industrial floors.	127	7	17	76	2	65	11	94	44	2	2008	2013	2018	2	13	25	95	6	2	12	17	16	24	33	73	3
ENER	Shared utilisation and other forms of intensification of product utilisation will be widely applied (with offers of providers and acceptance of clients).	131	4	21	76	6	57	41	84	33	3	2010	2014	2019	7	20	30	90	16	1	21	15	20	21	24	74	8
ENER	A wide-spread orientation towards product utilisation (instead of ownership) has evolved so that, e.g., a great number of privately used motor cars are not bought but rented from fleet management companies.	130	3	15	82	1	37	66	70	18	9	2012	2017	2022	19	47	25	70	14	3	14	8	10	3	15	78	15
ENER	Through widely used integrated product intelligence (IT systems) the residual functional properties of complex investment and consumer products will be determined and utilisation time and intensity can be prolonged.	110	5	19	76	6	57	26	75	21	8	2010	2014	2019	2	36	35	78	10	8	15	20	19	23	15	68	6

Source: Author.

- As to the *extension of product lives* a legal obligation to take back consumer goods will result in a practically closed material cycle in 2005. From 2008 the tendency to shorter innovation cycles will have reversed in favour of the intensification of utilisation and longer utilisation times of products. A tendency for dematerialization, especially using IT, is expected, covering the fact that from 2005 routine tasks will be taken over by software agents, by 2006 the majority of private households will use e-mail, the dematerialization of individual transport streams will break the link between economic growth and increased traffic by 2007, office work at home will be widespread by 2008. By 2012, the utilisation of electronic newspapers will reduce the amount of materialised information, and in 2013 electronic home shopping for up to 50% of all food items will have changed the role of specialised food merchants dramatically.

- Concerning the *intensification of the utilisation of products* the estimation of realisation times by the panellists suggests that there will be a pioneering phase with the development and application of enabling information technology: software agents for routine tasks and expert systems for company related services (financing, diagnosis, logistics) will be applied by 2007, IT systems which provide integrated product intelligence for static information (detailing how, at the end of its service life, a product can be disassembled and its component parts can be gathered and resources recovered from them) will become widespread by 2010, whereas dynamic information (determining whether the residual functional properties may be further used) will only be widespread in complex investment or consumer products by 2014. In general, the panellises express a long time horizon for the widespread realisation of these concepts: forms of intensification of product utilisation like shared utilisation (with offers of providers and acceptance of clients) are not expected to have been widely accepted before 2014, and product utilisation instead of ownership not before 2017, and for this concept a large share of the panellists showed a general reservation of not being realisable.

- For a broader utilisation of the concepts of *recycling, re-use and re-manufacturing* it is expected that a legal obligation to take back consumer goods will result in a practically closed material cycle by 2005. Again, integrated product intelligence comprising IT systems is judged to be a critical enabling technology. Re-manufacturing and re-use replacing the production of new goods will reach 50% of the turnover of industrial companies by 2013, and in 2017 an inter-firm coupled production ("zero waste production") may be widely applied – although a large share of the panellist had reservations as to the prospects for realisation of this thesis.

For most of these scenarios their contribution to the solution of ecological problems is rated as being above average, and often this coincides with a high rating for economic development. But from this material it also becomes clear that especially the realisation of such scenarios which are heavily dependent of a changed user behaviour cannot be reached by a mere offer of a newly developed technology. Even if changed regulations – and a change in regulations is being considered as the most important measure for realisation for almost all of the theses – can support the conditions for realisation, still a long adaptation period is characteristic for the diffusion of new behaviour patterns.

Interpreting foresight data and research priorities

Policy makers and strategic decision makers in all organisations of society need to get information input concerning their decisions as to future developments. And of course they would like to have this information as precisely as possible – forecasting rather than foresight is what they want. But an objective prediction of future scientific and technological development is not possible. Any study dealing with technological foresight can only provide ideas and add more information to a process of long-range thinking and planning (for a review of studies see Grupp 1993, and more recently Grupp 1999). Still there remains the highly important question – what can be learnt by foresight exercises with regard to research priorities? Two aspects of this topic will shortly be discussed here: methodological questions and the valuation of research priorities.

Methodological remarks

The primary goal of the Delphi '98 survey is to contribute to an understanding of the goals of science and technology. Neither current nor previous developments can simply be extrapolated to describe the future. Instead, what is involved are the expectations held by specialists – in other words, by those experts in the areas of science and technology whose activities help determine our technological future.

Furthermore, the general task of this survey must be taken into account: it is to inform the technically interested public on the complete variety of technologies. The specialist seeking answers to highly specific questions should seek other sources of information. But as specialisation tends to become extremely narrow, specialists are often poorly informed about other fields of science and technology which might well be of importance for their own field.

The examples given above concerning the "scenario" for concepts of production and product utilisation show very clearly that the survey raises as many questions as it answers. Quite a number of topics which might have been expected to be put before the experts do not appear, others are highly aggregated, and to a knowledgeable expert some may seem to be too topical or the results too well known. While all such criticism may be justified from a specialised perspective, it must not be disregarded that the Delphi survey deliberately intends to cover the complete spectrum of the longer-term future development of science and technology. This cannot but lead to severe but dedicated omissions. A survey covering the whole range of science and technology cannot be complete.

The kaleidoscope of the Delphi '98 survey only goes as far as 2025. Some future projects will not be undertaken by then. In some cases, innovations that could lead to a drastic and economically significant savings in resource efficiency may never come into being – at least based on current knowledge: in other words, they will probably not be undertaken within the foreseeable future. However, opinions tend to diverge on this point. We feel that, if 20% of the Delphi experts say "never", while the remainder indicate a time period beyond 2025, hope for the realisation of the innovation in question should be abandoned. This, in turn, is an assessment of our knowledge of the future.

On the other hand, a high rate of panellists rating a specific thesis as not feasible does not necessarily point to a severe problem but may as well be related to a certain interpretation of the thesis in question. This may be demonstrated with the following topic: while 24% of the panellists do not believe that an inter-firm coupled production will be realised using scrap from one company as materials input to another, there are several projects around the world (e.g. in Germany, the United States, Canada, Japan, the Netherlands) working on the realisation of this vision. They all follow the example of the "industrial symbiosis" or "eco-industrial park" which has developed during the past 25 years in the Danish town of Kalundborg. While some of the panellists may not have been familiar with these developments, in interpreting this question it should also be kept in mind that possibly in a very strict understanding, "zero-waste-production" throughout industry may indeed be impossible for physical reasons.

Similarly, the expected realisation periods should not be taken too literally. The accuracy of estimations is strongly and positively correlated with the time of realisation. Topics estimated to be realised earlier are easier to predict and accuracy of the judgement is higher. This finding was expected, as short-term innovations are easier to foresee than innovations. Innovations which the specialists feel can be realised by the year 2005 can be expected to appear in design stages or in prototype form at an earlier date, for example during the world EXPO in Hanover in 2000, that is why the judgements of the experts are rather identical concerning the time of realisation.

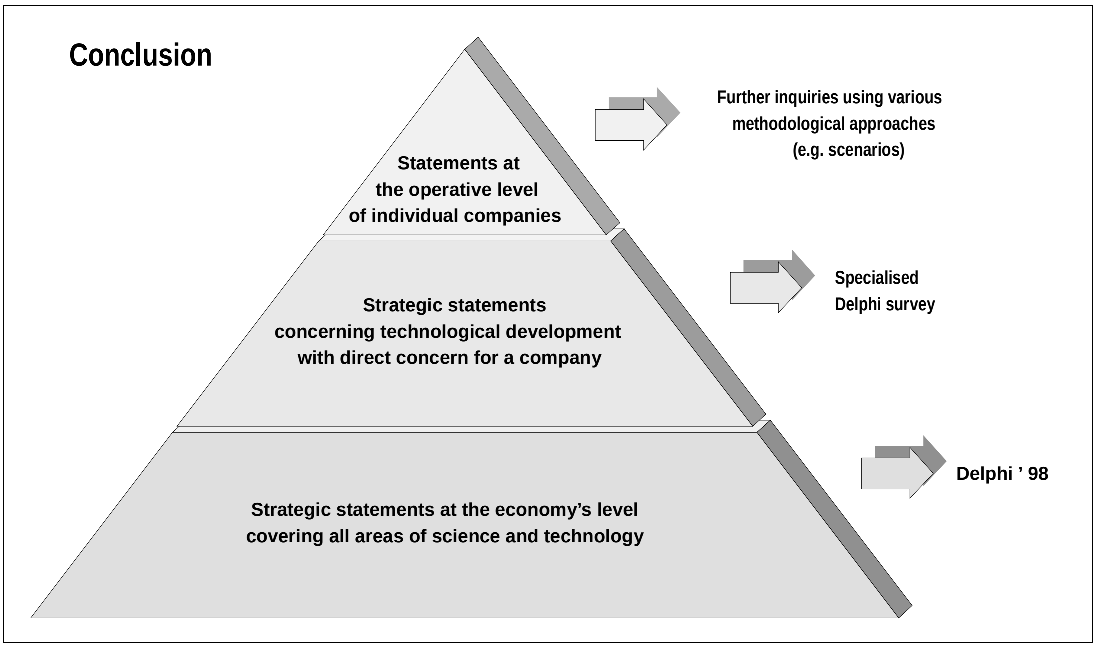
In sociology, most scientists assume that there is a positive relationship between involvement in a specific research area and the assessment of it and that this relationship derives from the tendency of scientists to select problems in areas where there is a high pay-off for successful solutions and a career. The tendency to overrate fields in which a person works may be termed "bias". Shrum (1985) found not only a tendency toward positive bias for fields in which researchers have been active, but also this bias to be stronger in less innovative sub-fields. A test for Delphi expert biases in the energy area (Shrum's investigation also dealt with energy research) tends to support this view in specific technology fields of the survey: active experts rate the importance of their own research speciality significantly higher than the other experts – both in Japan and in Germany (Breiner, Cuhls, Grupp 1994). At the same time, the top experts play down technical constraints in Germany (less so in Japan).

While for the analysis of environmental topics it would not have been adequate to restrict the analysis to the thematic field environment and nature, our procedure to include topics from all thematic fields raises a methodological problem. The information gathered in the other thematic fields has been collected in its respective context – without reference to it being relevant for resource efficiency, i.e. taking into account that the experts have answered from their specific perspective on the subject, we have to be aware that especially the weighting of importance will not be comparable: judgement of the importance of a question in the thematic field "mobility" will reflect the hierarchy of preferences for transport problems, not necessarily for environmental problems, although these might be heavily affected.

One main problem of a Delphi survey is the *generation of the foresight questions* asked. Regarding the research question of identifying those technologies which will have the greatest impact on economic as well as on social development, the creation of the questions is a very difficult task. In fact, to deal with the future of "sustainable development" would need questions to be developed from a scenario of one or more comprehensive and coherent possible futures. This has not been done, for reasons that may well be understood. But when building a scenario type of thematically coherent theses, this has to be kept in mind when interpreting the findings: where scenarios have not been put in they must not be read out.

The use of science-and-technology-wide Delphi surveys, specialised Delphi surveys and analyses using various methodological approaches (e.g. scenarios) is shown in Figure 4.

Figure 4. Use of different (technology) foresight methods for different tasks



Source: Author.

This figure illustrates the breadth and depth of the different approaches to (technology) foresight. The breadth of Delphi '98, as it covers all areas of science and technology, allows for strategic comparisons at the level of a complete economy/society. For strategic information of direct concern for an economic branch (and thus its companies), usually the complete breadth of a full range Delphi survey is not needed but information is required that digs deeper into the respective topics. A specialised Delphi survey covering a topic like "the future of the German health care system" (Jaeckel *et al.* 1995) will be the method to be chosen. For information that can be used for the operative activities of a company, however, results must be delivered in the necessary degree of detail and differentiation providing for completeness and consistency. For this reason a variety of different methods must be applied that have to be chosen according to the situation given for analysis.

Consequences for research priorities in environmental issues

There is no scientific way to determine *research priorities*, because all such determinations include value decisions which must be politically discussed and decided. Scientific investigations can, though, deliver and analyse information which is needed to allow informed decisions. This is what Delphi surveys and their scientific analysis aim at.

Because of the differing priorities of the aims of different groups of actors, the material of Delphi surveys has to be evaluated according to their respective frameworks of aims and means. To illustrate the possibilities concerning priority setting on the basis of Delphi survey results, this paper assumes the position of a decision-maker for public technology policy measures. Certainly one of the most important variables available from the survey is the estimation of importance of the topics by the expert panellists. Assuming a general situation of need for and shortage of financial means to support research and development activities, it would be advisable to concentrate on those topics which were rated as the most important ones among the 183 concerning the transversal issue of resource efficient technologies. But it would certainly not suffice for prioritisation to be based on this sole factor. For all other information collected in the survey there is no unambiguous way to evaluate and include the variables into R&D priority decision making.

Three practical examples will illustrate the possibilities of research priority setting on the basis of the information gathered in a Delphi survey:

(1) In technical syntheses the reaction and material separation steps will be process-integrated in a single device, for example by means of a reactive distillation or in a membrane reactor (c.f. Table 3).

This topic concerns the development phase of an innovation process, its realisation being expected in about the year 2011. The panellists rated this topic almost unanimously (98%) as important for economic development. Its importance for the solution of ecological problems (55%), in contrast, is rated rather below average. Almost all of the experts (91%) judge that Germany is leading in R&D in this field, but high rates also for Germany's strongest competitors -- the United States (42%) and Japan (31%) -- show that the competitive situation is far from being definite. For the necessary further development the most important measures are judged to be the improvement of the R&D infrastructure (67%) and third party R&D support (54%) which places this topic in the upper region of ratings for these measures. A likewise high rating of the exchange between science and industry (57%) also points to a strong need for further R&D. The rating for international co-operation is significantly below average (32% of the panellists) as an important measure for realisation which hints at the panellists' appraisal that a German lead in this field could be successfully turned into competitive advantage, possibly including the US and Japanese markets.

(2) The dematerialization of individual transport streams (e.g. rationalising and bundling goods shipments, tele-services for traditional supply functions for private households) will permit the link between economic growth and increased traffic to be successfully broken (c.f. Table 4).

For two decades or more, a majority of OECD Member countries have considered innovation (understood as practical application of processes or market entrance of products and services) and diffusion of supported technologies and solutions as one of the goals of public research and technology policies. Considering the goal of environmental relief, public policy aims at the widespread use of the best available solutions. This "far end" of the innovation process does not normally belong to research and technology policy, yet it can contribute to this goal.

From the evaluation of the topic of dematerialization of transport streams, which is judged of medium importance for the solution of ecological problems by the experts (74%) and for economic development (70%) there follows a series of aspects for a public policy: realisation time is expected rather late in the year 2015. Far under average ratings for improvements in the R&D system point to a diffusion problem. This is underlined by the fact that 58% of the experts point to the importance of a change in regulations for the realisation of this topic. Most probably there is no remedy from research and technology policy for this problem which may be one important reason for its expected late realisation. The intention of public policy to prioritise this topic might be derived from the expectation of gaining a "double dividend" of environmental relief and economic success.

(3) One example where research and technology policy (not other policy fields) can deliberately set a posteriority seems to be "because of new ecocycle regulations concerning packaging, measures will be taken to reduce the waste volume by 30% and the recovery traffic likewise" (c.f. table 4). This topic has been judged as highly important for the solution of ecological problems (89%) and of medium importance (57%) for economic development. The German R&D system is widely judged as being sufficient, and concerning the international position of R&D in this field Germany is seen far in the lead (94%) with the

United States and Japan hardly present (7% and 5%, respectively). The main constraint for realisation is seen here in a necessary change in regulations, as the formulation of the topic already suggests. So if there were not a possibility to reduce the amount of packaging waste generally through R&D, this topic would probably need no priority attention from research and technology policy.

These examples could only sketch the possibilities to analyse the material from the Delphi survey from the point of view of a decision-maker for research and technology policy. It has become clear already that the material requires further information in order to make priority decisions. Furthermore, it is necessary to include value decisions to achieve prioritisations. The same holds true, of course, for decision-makers in other policy fields and other organisations.

Concerning the usefulness of the whole investigation, it is expected that not only the analytical part of the Delphi survey will provide important information for future German technology policy but also that there was and will be an impact on the panellists themselves. Through answering the questions and checking their opinion with the anonymous assessments of other experts, the participants in the survey are likely to benefit from a learning effect. They were all provided with the estimates of other panellists in the course of the study and are free to make use of this information during their own future research and strategic decisions.

A Delphi survey is only one possible approach among many others to be used for technological foresight studies. Any technological foresight has to be integrated into global studies which also take into account social and economic developments in the future. Foresight can only contribute to a "better" future if *all aspects of human life* are integrated into a global picture. In order to develop detailed studies which consider technological as well as social and economic topics the scope of any foresight has to be restricted to certain aspects of the future – such as the development of a specific economic sector, or a societal bottleneck.

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ENVIRONMENT IN TECHNOLOGY FORESIGHT

by

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Summary

Technology foresight attempts tof identify important emerging technologies and to foresee broad *socio-economic trends* of the future for the objective of matching the supply of technologies to future societal needs. It is an invaluable tool for setting priority in research and development in an era of tight budgets. The creation of a sustainable socio-economic system is an important future need identified by Governments of OECD Member countries and foresight exercises target technologies, which are needed for achieving social goals in areas such as health and environment as well as economic objectives such as industrial competitiveness. Environmental issues are becoming predominant in foresight studies which highly rank technologies for achieving sustainable development goals.

Some major OECD foresight studies conducted in this decade, including major Delphi survey based studies, critical technologies studies, and consultation based studies, identify certain common technological themes relevant for sustainable development objectives. These include: advanced sensors, biotechnology, clean car technologies, product recycling, smart water treatment, smart waste and hazardous substance treatment, micro-manufacturing for cleaner industrial processes, photovoltaics and other renewable energy sources.

Environmental technology is not a distinct discipline-based field. It is a technology defined by its objective of protecting the environment, whether it be biotechnology or information technology. Foresight results show that environmental technology is diffuse and often interdisciplinary. Moreover, technologies relevant for the environment are intertwined and interrelated. Because of this, forging linkages and network building between researchers in different disciplines and in different research sectors (government, industries and universities) is especially important. Environmental technologies also require long time horizons to develop. Sustained government research support is crucial in areas where industry may under-invest. Environmental policy tools such as regulation, standardisation and green procurement as well as fiscal and pricing policies need to be combined with technology policy in driving the development of the key technologies, which will underpin sustainable growth in OECD countries. The growing stress on global environmental issues reveals a need for better understanding and monitoring of global-scale phenomena, and demonstrates the need to strengthen long-term international S&T co-operation. The process of technology foresight itself is valuable in forging linkages among researchers and between society and research. Environment-related technology foresight is creating networks of people sharing a common view of how to realise a sustainable future.

Introduction

Technology foresight activities have proliferated in the OECD area in the present decade. This stems from the recognition of the increasing importance of new technologies for industrial competitiveness and in achieving social objectives. It is also related to the need for priority-setting in research under current public expenditure constraints and the increasing complexity and diversity of contemporary technologies which are rapidly pushing up the cost of research and development. Through foresight exercises, important new technologies can be identified on which governments and industries can target resources for development.

Technology foresight can be defined as "*systematic* attempts to look into the *longer-term* future of science, technology, economy and society with a view to identifying *emerging generic technologies* likely to yield the greatest *economic and/or social benefits*" (Martin, 1996). The longer-term future normally means a typical horizon of ten years, but can range between five and 30 years. Foresight exercises involve balancing "science/technology push" with "market pull" to identify technologies, which are still at a pre-competitive stage of development, and which, therefore, legitimise government support. Attention is given not only to the industrial and economic impacts of new technologies but also to social benefits including effects on the environment.

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

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

Environmental technologies for the future

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

The predictions regarding the important environmental technologies of the future made by the most recent technology foresight surveys in the OECD countries are described in the subsequent parts of this paper.

While these vary by country and by foresight exercises within countries, certain common technological themes relevant for sustainable development objectives emerge. These point to a range of diverse technologies in different fields and of varied types. The consensus list of important environmental technologies for the future would include the following:

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

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

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

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

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

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

- **Cleaner industrial processes and micro-manufacturing.** Industrial processes of the future will use less material and energy and produce less wastes and hazardous emissions through the use of advanced biological and chemical catalysts, advanced separation and energy efficient technologies. Radically cleaner processes could eventually feature micro-technology which could be used to produce a wide range of products from chemicals to energy in de-centralised production units with reduced environmental impacts.

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

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

Foresight methodologies and the environment

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

The technology foresight undertaken in the OECD countries today evolved from the technology forecasting conducted in the US defence sector in the 1950s and 60s, where important foresight tools such as the Delphi survey and scenario analysis were developed. These methodologies remain key tools of current foresight activities. The Delphi method has been taken up by the Japanese government forecasting exercise, the only foresight activity conducted every five years since 1970. In other countries, interest shifted more toward broader foresight or *la prospective* toward the second half of 1980s. Whereas the technological forecasting approach assumed the existence of a unique future, which was to be predicted as accurately as possible, the foresight approach assumes, instead, the existence of numerous possible futures, the realisation of which depends on choices made today. Therefore, compared to forecasting, foresight "involves a more "active" attitude towards the future" (Martin, 1996).

Since the 1980s, the newer foresight approach gained popularity with its methodology and procedures becoming more elaborate and diversified. In the current flourishing of technology foresight exercises, a vast array of methodologies are used There are still considerable methodological problems for various studies to be sufficiently comparable, because of the differences in terms of size, disaggregation, methodology and relevance, as well as the lack of technological details and comprehensiveness of assessments and recommendations for technology policy (Grupp, 1996).

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

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

Despite the active use of methods employed by others, foresight studies tend to be unique, and the method and the questionnaires (in case of Delphi) reflect the specific research and innovation system and interests of the country. Each study builds and modifies on past experiences and studies undertaken in other countries. In the process, the original technological forecasting methodologies became parts of broader foresight exercises which include other activities such as panels and critical or key technology listings.

Many governments attach importance to the *process* involved in a technology foresight exercise. The interactions involved generate important feedbacks to researchers and policy makers, and this process in which "one comes to a better understanding of the forces shaping the long-term future" (Martin and Irvine,

1989) leads to general consensus-building among experts and policy makers in actively creating paths to a desirable future. The interactive nature and an active attitude toward the future characterise recent foresight exercises in the OECD area.

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

Delphi survey-based studies

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

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

Japan: Fifth Delphi survey

This survey was conducted in 1991 with a forecast period to 2020. A total of 1 149 topics were classified into 16 technological areas by a steering committee and 13 sub-committees. The response rate was about 80% in the two survey rounds. The general results showed: 1) the fields of environment and life science had the highest percentage of topics (50%) for which a majority of respondents attached a high level of importance, and 2) topics with a high level of importance were related to a healthy and secure lifestyle which involves the preservation of the environment, conquest of diseases and disaster prevention.

The survey extracted topics whose “relationship with environmental issues is regarded as important”, which corresponded to about 19% of the topics, and which included not only those technologies that *directly* solve environmental problems but also *indirect* technologies. Therefore, the environmental category was defined to include technologies that: 1) are related to measurement, monitoring and prediction of environmental changes, and the elucidation of principles and mechanisms of environmental changes; 2) technologies that contribute directly to solving environmental problems including pollution prevention, control and remediation technologies; and 3) "indirect" technologies whose main objective is not environment but the use of which would also contribute to the solving of environmental problems. The category covered topics related to global environmental issues as well as conventional and local pollution issues. The survey noted that some environmental issues such as measures for global warming would require combining technologies in not only the environment area but also energy, production, materials and processing, outer space, as well as marine and earth sciences to arrive at elucidation, monitoring and effective countermeasures (Kagakugijutsu Seisaku Kenkyusho, 1992).

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

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

- Technologies that will eliminate NOx and other pollutants that cause today's air pollution.
- Technologies for CO^2 fixation, artificial photosynthesis, treatment of hazardous wastes and prevention of desertification.
- Development of normal temperature superconducting materials.
- Development of a safety system for industrial and (nuclear) power plants which prevents destruction of plants by earthquakes.
- Technologies for segregating valuable substances in urban refuse for their retrieval.
- Technology to transform solar energy into biochemical energy.
- Waste re-use technology that reduces municipal waste by half.
- Safe and efficient demissioning of commercial nuclear power plants.
- Technology to treat solid high radioactive waste.
- Product recycling technology.
- CFC substitutes which do not deplete the ozone layer nor contribute to global warming.
- Faster speed-train tracks (300km/h) and an environmentally acceptable *shinkansen* train.
- Photovoltaic cells with more than 50% conversion efficiency.
- Dryness and salt resistant plant strains to prevent desertification.
- Low emission technology (NOx emission of 0.1-0.2g/km) for automobiles.
- Biodegradable packaging material.

Source: Kagakugijutsu Seisaku Kenkyusho (1992).

Germany: Delphi I

Interest in technology foresight developed rapidly in Germany in the early 1990s because of the unification of the country and the ensuing tasks involved in restructuring a former socialist economy, as well as the budget constraints resulting from the unification and the worldwide economic recession (Grupp, 1996). Thus the first Delphi survey was conducted in 1992. The exercise was modelled closely on the Fifth Japanese Delphi survey and conducted a year after it. Japanese Delphi topics were translated into German and used except for those that did not apply in the German context. The results of the two surveys were thoroughly analysed and compared (NISTEP, 1994; Cuhls and Kuwahara, 1994).

Overall results showed fairly strong similarities, especially in the time of realisation of the surveyed topics. In both surveys, the index of importance was the highest in three technology areas, environment, medical care/health, and life sciences. Other environmentally-relevant technology areas that had an average or higher than average index of importance in both countries were urbanisation and construction, marine and earth science and energy. The forecast realisation time for technologies in the environment area and environment-relevant areas (materials and processing, marine and earth science, mineral and water resources, energy, agriculture forestry and fisheries, production, urbanisation and construction, and transportation) are similar, and are forecast to be realised in the medium range of between 2005 and 2009. The list of the ten most important technologies in the German survey includes five environmentally-relevant technologies, three of which had an importance index of more than 80 in the Japanese survey (**Box 2**). On the other hand, the two environmentally-relevant topics in the top ten list in the Japanese survey were rated with an importance index of 95 in Germany. These were 1) technologies that will eliminate the NOx and other air pollutants; and 2) technologies for global environmental preservation, including absorbing carbon dioxide, artificial photosynthesis, turning wastes into harmless substances and preventing desertification.

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

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

Source: Cuhls and Kuwahara (1994).

Japan-Germany Mini-Delphi survey

One outcome of the first German Delphi was a joint Japanese and German undertaking in which the Mini-Delphi method was designed. Topics were jointly created by a committee of experts from both countries and surveyed simultaneously in both countries, and the results published in Japanese and German (Kuwahara *et al.*, 1995). The technology areas as well as the range of topics in each area were narrowed to four technology areas (with two sub-areas in each) and 120 topics. However, since a provision was made in the first round for respondents to be able to suggest topics which they thought were important, the number of topics increased to 132 in the second round. Assessment criteria were contribution to the development of: 1) science and technology, 2) the economy, 3) the environment, 4) developing countries and 5) society.

The results of the assessment of “importance for the environment” revealed that technologies in the areas of photovoltaics, waste treatment and global climate change were rated with indices of high importance in both countries. Technologies in the areas of superconductivity, nano-technology and artificial intelligence were rated at about average level of importance. Topics that received the highest ratings in both countries (index of more than 90 in both countries) were: 1) CFC substitutes, 2) soil remediation by the use of micro-organisms, 3) renewable energy sources, 4) technologies for monitoring pollutants in atmosphere and water, and 5) residential photovoltaic systems. In the sub-area of waste treatment, there was fairly close agreement between the two surveys in the assessment of importance for environmental amelioration. Bio-remediation, recycling systems and the development of environmentally compatible materials are considered important by experts in both countries. Most topics in this sub-area are forecast to be realised between 2002 and 2017. As for topics in the global climate change sub-area, both countries attached highest importance for the objective of environmental amelioration to CFC substitutes and curbing of CO^2 emissions.

French Delphi

The French Delphi exercise, which was also modelled on the Japanese Delphi, arose “from a recognition of the need to improve the technological vision of the government and to provide a more systematic approach to priority setting” (Martin, 1996). Since there was little experience with Delphi in France, the exercise was launched “on an experimental basis” and viewed in the country “more as the study of fledgling technological dynamics and the clash of major global trends than as an exercise in prediction” (Quévreux, 1996). Technology areas except that of “life and culture” of the Japanese survey were used however, topics were translated from the German questionnaire. The document compiling the results was published in 1995 (MESR, 1995).

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

Japan: Sixth Delphi survey

This survey conducted in 1996 narrowed and redefined technology areas to 14 by: 1) dividing “information and electronics” into “information” and “electronics”, 2) combining “mineral and water resources” and “energy” into “resources and energy” and 3) removing “particles” and “life-style and culture” as technology areas and incorporating these topics in other areas. The same criteria were used for the forecast period to 2025. Comparing the topics in the fifth and the sixth surveys, many new topics are found in the electronics and information technology areas whereas the environment-relevant areas of “environment”, “marine and earth science”, and “resources and energy” include relatively fewer new topics. This may imply that in the present phase, the pace of innovation in information and electronics is very rapid, and many new, important topics come up within a relatively short period of five years, whereas in environment-relevant areas, topics which were recognised to be important five years ago largely remain unrealised (Kikuta, 1998). While the yet basic nature of the research and the complexity of topics in environment-relevant areas may, in part, explain this lag, the weakness of the market pull for environmental technologies in comparison to technologies in information and electronics, may well be a major factor that is slowing down the pace of research and innovation in the environmental area.

In the assessment of importance, topics in the environment area were rated with the highest degree of importance at an index of 72.0, while the average for all topics was 62.1. Among the 100 topics with the highest importance ratings, 25 environment-related topics and 11 new energy topics are found. Compared to the fifth survey, there are more technologies related to recycling and photovotaics and fewer on global environment. Starting from the highest degree of importance, these technologies are found in **Box 3**.

Box 3. Highest ranked environmental technologies in Sixth Japanese Delphi (expected realisation in parenthesis)

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

Source: NISTEP (1997).

Germany: Delphi 98

In 1995, the German BMBF decided to launch the second Delphi survey, which this time, was designed independently in Germany. 1 070 topics covering the 12 technology areas, were surveyed among 7 000 experts in 1997 and the results published in 1998 (Fraunhofer Institute and BMBF 1998). Based on the results, the steering committee presented 19 megatrends that will influence science and technology of which three were related to environmental issues, which give a rather morose outlook for the future:

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

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

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

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

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

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

Source: Fraunhofer Institute and BMBF, 1998.

United Kingdom: Technology Foresight Programme

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

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

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

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

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

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

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

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

Comparison of Delphi surveys

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

Box 5. Priority environmental research areas in the United Kingdom

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

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

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

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

Source: Foresight Natural Resources and Environment (1998).

Box 6. Highly ranked environmental technologies in Four Delphi Surveys

Construction:

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

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

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

Global environment:

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

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

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

Power generation:

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

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

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

Source: Gavigan and Cahill (1997).

Critical technologies studies

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

Germany: T21

Undertaken along with the first Delphi survey, the study aimed to identify technological trends and their possible commercial applications in the time horizon of ten years. It started by a selection of critical technologies, then using relevance trees, the contributions of future technology to solving societal, ecological and economic problems and bottlenecks were clarified. The project also aimed to mobilise for foresight purposes the in-house expertise of German research administrators by naming several *Projektträger* (programme operators), agencies mostly located in the national laboratories to assist BMBF and the Fraunhofer Institute for Systems and Innovation Research, which was charged with the design and execution of the study.

The initial selection of critical technologies produced a list of about 100 technologies which were then redefined and regrouped in bilateral and panel discussions, by "searching for relationships, areas of overlap and evidence of cross-fertilisation between scientific or technical lines of development previously regarded as unconnected" (Grupp, 1994). The exercise revealed technological overlaps, blurring of borderlines between individual technologies and new disciplines being shaped outside classical research areas. The study then grouped critical technologies under nine generic headings (advanced materials, nano-technology, microelectronics, photonics, microsystems engineering, software and simulation, molecular electronics, cellular biotechnology, and production and management engineering), and assessed them as to the contributions they could make towards solutions in the following areas: construction technology, energy technology, food technology, medical technology, exploration technology and security of raw materials (including recycling), environmental technology and transport technology. Results showed that all generic technology areas could potentially make contributions to environmental technology. Most technologies in advanced materials and cellular biotechnology were potential contributors to environmental technology (Grupp, 1996).

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

France: 100 key technologies

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

The next step was to organise expert groups which met periodically (1993-1994) and used the criteria to identify technologies in five "market pull" areas (health and environment, services and communication, transport systems, consumer goods, housing and infrastructures) and five "technology push" areas (life sciences, information technology, energy technology, "soft sciences" and production management techniques, materials and associated technologies). At the end of this stage, from a total of 676 technologies, 136 technologies were selected by the steering committee as being particularly important. In the third phase, the competitive position of the French industrial sector and the scientific lead of the French research sector in these technologies were assessed. The results were synthesised in the fourth phase to identify and characterise these technologies in terms of the relative strength of France, attractive attributes and conditions of success. In the end, 105 technologies were labelled "key technologies" including the environment-related technologies listed in **Box 7**.

US national critical technologies panel

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

Box 7. Critical environmental technologies in France

Health and environment area:

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

Transport area:

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

Materials:

Intelligent materials.
High temperature resistant materials.

Energy area:

Biomass conversion.
Clean and safe nuclear energy.
Photovoltaics.

Housing and infrastructures:

Management of water resources.

Production, instruments and measuring:

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

Source: Ministry of Industry (DGSI), (1996).

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

Consultation-based studies

Some foresight studies involve wide and extensive consultation with experts to draw up important technological trends. This approach attaches importance to the interactive process and the creation of a common vision.

Australia: ASTEC study

The Australian Science and Technology Council (ASTEC), in *Matching Science and Technology to Future Needs 2010* (ASTEC, 1996), attempted to examine Australia's key future needs and opportunities and ways to match scientific and technological developments to these needs through an extensive consultative process, for the objective of improving Australia's long-term economic competitiveness and social and environmental well-being. The exercise consisted of a set of four parallel activities. In the first phase, supply and demand issues in science and technology facing Australia were examined through extensive consultations using workshops and roundtables. The exercise identified "Key Issues for Australia to 2010" in six areas: 1) for innovation and entrepreneurship, 2) for a technologically literate society, 3) to capture opportunities from globalisation, 4) to sustain the natural environment, 5) for continuous improvement in community well-being, and 6) to build a forward looking science and technology system. In the second phase, ASTEC formed partnerships with other organisations which carried out foresight studies of specific areas: health, urban water life cycles, shipping, youth, and information and communication technologies. The third phase reviewed other foresight exercises in Australia and other countries, and in the fourth phase, ASTEC commissioned a study of the impact of science and technology on economic growth as a means of assisting in ranking the priority of science and technology issues.

These activities led to the identification of Key Forces for Change which formed the basis for the strategy to be recommended to the government. Also, as a part of the study, ASTEC identified six generic "critical technology" areas for the 21st century: 1) environment (including energy), 2) transportation, 3) information and communications technology and electronics, 4) genetics and biotechnology, 5) manufacturing and precision and control in management, 6) materials.

Box 8. Critical environmental technologies in the United States

Energy:

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

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

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

Environmental quality:

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

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

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

Living systems:

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

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

Manufacturing:

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

Materials:

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

Transportation:

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

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

Source: US National Critical Technologies Panel (1995).

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

Netherlands

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

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

The study by the *Foresight Steering Committee* set up by the Ministry of Education Culture and Sciences attempted to identify research priorities in the longer time horizon of ten years or more. Objectives were to: 1) stimulate the process of foresight in the research sector, and 2) to formulate policy options on the basis of the results. The foresight process involved establishing a working dialogue between experts from both the supply and demand sides of research with the view to organise the Netherlands national knowledge system in a manner that would satisfy the demand for knowledge in the future. The Committee was presented with a list of issues which covered not only the areas of science, technology and engineering but also the associated areas of social science and the humanities. As a result, 16 separate studies were undertaken.

The study identified a number of "knowledge themes" for future research. With regard to the environment, these included a National Research Initiative Factor 4, aiming to reduce environmental impacts drastically through:

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

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

- Process technological, catalytic and biotechnological research focusing on processes which allow the maximum level of purity to be achieved in the end product while minimising residual products; chemistry research aiming to transform those products into raw materials.

- The development of sustainable industrial systems in agriculture, for which multidisciplinary programmes focusing on the development of model systems based on biological, technological and socio-economic research are important.

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

None of the foresight studies discussed so far focused specifically on technologies relevant for the environment. One of the most recent foresight exercises in the Netherlands - *The 81 Options: Technology for Sustainable Development* - was undertaken with this focus. The exercise started by identifying 2 500 environment-related technologies from the results of both foreign and Dutch foresight studies conducted in this decade. Then the positive or negative impact of the technologies was assessed in terms of: 1) utilisation of fossil fuels, 2) use of scarce raw materials, 3) emissions and 4) waste. The process resulted in identifying 81 "technology systems" which had environmental relevance for the Netherlands in the 15 to 25 years to come (Weterings *et al.*, 1997).

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

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

Box 9. Important environmental technology clusters in the Netherlands

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

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

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

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

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

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

Conclusions

Despite the divergence in structure of the technology foresight exercises reviewed here, the environment-related dimensions of these studies converge in certain aspects. Sustainable development is generally viewed as a key future need to which science and technology should be directed. Some foresight studies are exclusively devoted to the environment. All of the foresight studies attach high importance to environment-related issues and the technologies relevant for achieving sustainable development objectives. The Delphi surveys include environment as a technology area, and environment-related technologies are rated to be of higher importance than many others in these studies. Many foresight studies adopt relevance for improving the environment as a major criterion of importance for selecting technologies of the future.

The Delphi surveys emphasise that many of the emerging environment-related technologies take long time horizons to develop, in contrast to information technologies for which the time horizons are short. This is due, in part to the yet basic nature of the research and the complexity of topics in environment-relevant areas, and perhaps more importantly, to the weaker market pull for environmental technologies than for information technologies. This points to the importance of sustaining support to develop environmental technologies through focused research policy, and to judiciously combine technology policy with environmental and fiscal policy tools to bring suitable innovations to the market place more rapidly. The growing stress on global environmental issues reveals a need for better technologies for understanding and monitoring global-scale phenomena. This also illustrates the need to strengthen international S&T co-operation in the long-term to assess, understand and track environmental changes such as global warming, desertification and atmospheric factors.

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

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CRITICAL TECHNOLOGIES FOR THE ENVIRONMENT

by

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Introduction

Two issues associated with technology forecasting have been the focus of efforts at Pacific Northwest National Laboratory (PNNL) over the past year. The first is, "What technologies benefiting the environment are likely to impact consumers over the next decade?" and the second is "How does one create a coherent technology strategy in response to the desire to reduce greenhouse gas emissions over the next century?" These two questions have been and are being addressed in two very different ways.

The first question has been addressed using a method developed at Battelle Memorial Institute by Steve Millett. Battelle has been heavily involved in the forecasting of R&D and technology trends for several decades. Its most well known product is the annual R&D forecast which it produces in conjunction with R&D magazine. More recently Millett has helped a series of "Top 10" forecasts of future technologies which have been designed to look out a decade at the future of practical technologies. Millett's approach was used at PNNL, which is managed by Battelle for the Department of Energy, to forecast the "Top 10 Environmental Technologies for 2008". This list was designed to identify technologies that specifically affect consumers and yield positive environmental benefit.

The second question is how one informs a broad technology strategy rather than forecasting specific technologies. Here the method is based on the work of Jae Edmonds and his colleagues of PNNL's Global Change Research Group. Edmonds has been trying to understand how suites of technologies might develop that cost effectively allow the world to achieve the goals of the Framework Convention on Climate Change. The stated goal of this treaty, one of the major products of the 1990 Earth Summit in Rio, is to stabilise atmospheric carbon dioxide concentrations below "dangerous" levels. Edmonds' work is in its early stages and uses a global economic model to analyse both the generation and consumption of energy. This model, known as the "Second Generation Model" is a derivation of the Edmonds-Reilly model, which has, for most of the last 15 years, been a primary model for the prediction of long-term atmospheric carbon dioxide concentrations.

The second section of this paper describes the process used and the results of the "Top 10" analysis. Since the nominal group technique is an "expert" process, the section also tries to describe some of the factors that drove that expert process. The third section describes the context of the work on global change. Since the results of that work are not yet complete, the emphasis will be on the drivers of technology as one attempts to address the stabilisation of atmospheric carbon dioxide concentrations. These drivers are illustrated using an example approach to the stabilisation of atmospheric carbon dioxide concentrations. The final section summarises some of the underlying principles in each of these analyses and the considerations that will dominate our future work in these two areas. This paper is not intended to be an exhaustive academic treatise on the methods employed, but a narrative that highlights the basic considerations and results of the two analyses.

The top 10 environmental technologies for 2008

While many technological forecasting and foresight activities have very strong national and international drivers, our work on the "Top 10 Environmental Technologies for 2008" did not. Some foresight activities are used by smaller nations to select key technological areas in which they can focus their limited R&D resources; ours served several very different and distinct purposes. PNNL is a large laboratory with approximately 3 400 staff. Its research focus is environmental science and technology. As a DOE National Laboratory, much of the work is focused on some of the largest environmental problems, such as environmental restoration in the wake of the shutdown of the plutonium production complex associated with the maintenance of the nuclear stockpile during the Cold War. It also is a basic research enterprise in which there is work not only on such large problems as global change, but also some fundamental research into the nature and evolution of microbial ecosystems found deep beneath the surface of the Earth. Our challenge is to anticipate areas of research and to continually relate our work to the interests of the general public who provide the funding for this enterprise. Our "Top 10" exercises are designed to partially meet these goals.

Our goal in creating this list was to generate a credible list of technologies with several characteristics. Specifically we wanted to identify technologies that had:

- Breakthrough characteristics, representing significant departures from current practice.
- Clear connection to major environmental issues.
- Direct impact on consumers.
- Some clear likelihood of being realised on the time scale of a decade.

The methodology for this exercise was the nominal group technique. This technique uses an expert panel assembled, in our case, for one day to brainstorm candidates for the list and to systematically evaluate these candidate technologies against the criteria to create the final list. Battelle Memorial Institute, the operator of PNNL, has used the nominal group technique for several years to create a variety of technology forecasts.

The Panel was made up entirely of staff of PNNL and other parts of Battelle. This design has some advantages and disadvantages. Certainly, the discussion could have been enriched by broader participation, but this more limited group, many of whom had worked together before, could focus not only on the task at hand but could also carry the results into their respective research groups, informing their respective long term research agendas. The group comprised about 12 individuals and was selected to span basic research to practical application. It also included individuals knowledgeable in the various research disciplines, such as ecology, engineering, atmospheric science, economics, and geosciences.

The meeting was organised into four segments:

1. A context setting discussion of the drivers of environmental technology. This discussion had two discrete phases. One phase covered both the underlying environmental drivers as well as emerging environmental issues. The second phase covered long term technological trends.

These two discussions tried to focus the conversation around those issues and technologies that would manifest themselves most strongly in the next decade.

2. In the second segment, the group brainstormed a list of technologies which might be included on the eventual list. Approximately 60 different technologies of varying specificity were identified. Once the list was complete there was a brief discussion and some consolidation was made.

3. The third segment was a straight multi-voting process, in which each of the panel members voted for the seven technologies that they felt belonged on the final list. The votes were tallied and the list was reduced to approximately 14 technologies.

4. In the final segment, the group reviewed the list against the criteria and a final list of ten was agreed to.

Each of these segments had some interesting aspects that are worth noting.

Context setting

The discussion of the context began with what could be called the Corollary to the "law of unintended consequences". This "Law" highlights the fact that no matter how hard one tries to engineer the perfect system there are collateral effects of the system or technology that are entirely unanticipated. The "corollary" that evolved during the discussion was the recognition that practically every environmental problem is the direct consequence of a previous solution. That is to say, if one views environmental problems as solutions to technological infelicities, one also has to recognise that in most cases the original technology itself was a solution – a better way of doing things. It was further noted that there was a very real risk that an environmental solution could in fact have unintended and harmful environmental effects as well. While there was a recognition that the systems approach to engineered systems exists, such as life cycle analysis, the risk was a real one.

The context setting included an extended discussion of emerging environmental problems and concerns. Among those discussed were:

- **Diffuse source pollutants**: As clear point source polluters are confronted by regulation and new technology is introduced, the cumulative effect of many small polluters is becoming more and more important as an environmental problem.

- **Food safety**: While not normally seen as an environmental problem, it was noted that most environmental regulation is driven by health concerns. When one begins to generalise the concept of the environment to those pollutants that enter the food chain the feeling was that this was an area that would be increasingly a concern of consumers.

- **Endocrine disrupters**: The chemical interference with basic biological processes is just beginning to be understood and is an increasing concern. This represents a movement away from the classic focus on carcinogenesis and toxicity, to other human health consequences.

In addition to trends in environmental issues, the group also discussed technological trends that would drive the evolution of consumer products and industrial technologies. As noted above the eventual focus of the final list was to be on breakthrough technologies. As a result three specific technology trends emerged from the discussion as being important drivers of broader technological change:

- **Moore's law**: This well-known expression of the rapid evolution of electronic and computer technology was seen as a continuing technological driver over the next decade.

- **Nano- and micro technology**: The group saw the evolution of other "small scale" technologies as emerging in importance over the next decade. The question as to whether this would lead to other Moore's Law like relationships for mechanical or chemical processing systems was left open.

- **Biotechnology magic**: Biotechnology was seen as great potential, but it was not clear what barriers may emerge to the adoption of new technologies based on these approaches in general, and genetically manipulated organisms in particular.

Generating the final list

The process outlined above resulted in a long list of possible technologies and the remaining process of winnowing the list down to 10 items had three critical elements. These elements can best be understood by considering the following questions:

- Were the resulting technologies consumer focused technologies? The emphasis here was not to determine whether the product or technology was a consumer product *per se*, but rather that it would either be or affect a product in widespread use. As a result the final list includes products used directly by consumers, while others are upstream of major consumer products.

- Did the technologies represent a breakthrough? Rather than trying to anticipate broad trends in consumer products, the goal was to identify technologies that represented a major advance, fulfilled a stated or unstated need and had the potential to create a whole new business or industry.

- Finally, was it likely that the technology would have an impact in the next decade? It is always difficult to determine the rate at which some technologies will have widespread use and the group tried to be realistic about these projections.

The list

The final list was generated through a voting process, which in some sense gave an order to the list. The list is reported below in that order but apart from the first two entries the order is probably not significant. Because of the significance of food and water to civilisation broadly, the first two items were clearly seen as broadly important technologies, not only in technologically developed countries but also in the developing world. Since the list was generated partially to engage the public in thinking about environmental technology, it is presented using the same "catch phrases" used in the publicly released list.

1. ***Agrogenetics***: Genetic engineering of crops was seen as an important path forward in the reduction of the environmental impact of agriculture. This technology was seen as important not only because of the potentially positive impact on the environment, but also because of the importance of increasing yield. It was recognised that there is continuing debate about the introduction of genetically modified organisms into the environment. However, it was felt that over the next decade this concern would be resolved in favour of the technology.

2. ***Smart water treatment***: Water is one of the principle pathways by which people are exposed to environmental contaminants. The concern about these contaminants was seen as driving the development of even more powerful end-user filtration systems with such features as self-cleaning filters and the capability of removing wider and wider ranges of contaminants. The potential of these technologies to help in the developing world was also noted.

3. ***Renewable energy storage***: The development of new power storage technologies will mean solar power at night, wind power in calm weather. Long a barrier to the widespread use of some renewable energy sources, storage technologies were seen as moving to new levels of performance in cost and energy density over the next decade.

4. ***Micro is beautiful***: The drive to miniaturisation will move beyond computer chips to other applications, most notably thermal and chemical systems. Microtechnology, and its associated improvements in system efficiency, were seen as leading to a new generation of heat pumps, chemical separation, and combustion systems.

5. ***Paperless society***: Despite the fact that the development of the laser printer has probably destroyed the vision of the paperless office, increasing use of electronics was seen as putting pressure on other forms of paper product. In particular, the improvement in displays and the electronic transmission of energy were seen as impacting distributed print media, such as books, newspapers and magazines.

6. ***Molecular design***: Increasing ability to understand and manipulate materials at the molecular level was seen as improving everything from sensors to catalysts and leading to chemical processing systems generating substantially less waste.

7. ***Bioprocessing grows products***: While agriculture is on the one hand seen as a source of environmental degradation, the possibility of using plants to grow drugs, proteins, enzymes and fuels was seen as a major change in the next decade. At the microbial level the development and use of extremozymes in enviro-friendly industrial processes was seen as one of the great benefits of biotechnology.

8. ***Real-time environmental sensors***: Sensor technologies offer a dual benefit allowing not only more effective control of processes but also the real time detection and control of contaminants in the environment. Both food safety and air quality in buildings may be checked continuously by new generations of sensors.

9. ***Enviro-manufacturing and recycling***: Increasingly, through knowledge of industrial ecology and life cycle analysis companies will imitate natural cycles with their products for less environmental impacts. Concepts, such as design for reuse or recycle, were seen as being an increasing feature of the products offered to consumers.

10. ***Lightweight cars***: Throughout the world the automobile is one of the most significant environmental challenges. A great deal of change will be made in those vehicles in the next decade, including major power plant changes. Increased use of lightweight materials, such as aluminium, titanium, magnesium, plastics and composites will lead to vehicles that use less energy but preserve both safety and price performance.

As we looked back at the list, we noted three trends emerging over the next decade several of which reflected our context setting discussion. We saw continued concern about point source polluters and the evolving diffuse source issue play out in several technologies. New technologies, such as biotechnology and microtechnology, were seen as penetrating traditional manufacturing. Technologies addressing threats to health coming through the environment were seen as moving into the consumer market in sensors and personal treatment systems. Finally, in storage systems and lightweight vehicles we saw the bow wave of climate change related technologies is just appearing as the decade came to a close.

Carbon management

The problem of long range technological forecasting is more complicated than the expert extrapolation of existing trends. It is, however, extremely important if one wants to develop a technological response capable of reducing global carbon dioxide emissions. It is the most challenging environmental problems of the next century. At PNNL we have been developing an approach to this designed to address the questions of “what does the time evolving technology portfolio look like” and “what are the areas in which research might have a high impact on the portfolio”. This effort, called the Global Technology Strategy Project, uses an economic model as the basis of analysis of the technologies, under the assumption that the cost effectiveness of the technology is going to be a major determinant of market penetration. While this programme is in its early stages, it is providing some insights into the factors controlling the utility and timing of sequestration technologies and the timing and role of solar technologies. In what follows, the general problem is outlined and our current understanding of the drivers is given.

If atmospheric carbon dioxide concentrations are to be stabilised, carbon dioxide emissions to the atmosphere must be reduced. It is therefore necessary to look into the factors that underpin carbon emissions. One way of looking at the situation is to view carbon emissions as the product of population, GDP/capita, energy/GDP and carbon/energy. In order to reduce or control emissions it is essential to reduce or control one or more of these four items. This is generally referred to as the Kaya equation in which:

CO_2 Emissions =[Population x GDP/capita x Energy/GDP

x CO_2/Energy] **-** [CO_2 captured from the atmosphere].

The last term, a sequestration term, suggests that it is possible to capture carbon dioxide from the atmosphere to offset emissions.

The Kaya equation suggests several strategies that might be developed to reduce atmospheric carbon dioxide emissions. At the outset however, it should be noted that while population is an important issue and stabilisation is important, reducing emissions by general population reduction is not an option. Similarly, even though economic growth represents the primary pressure on carbon emissions into the next century a carbon emission control strategy based on the reduction of economic well being is also not an option. The remaining three levers, efficiency, carbon intensity and atmospheric capture are all technological channels that could be used to reduce emissions, with a myriad of possible technological pathways possible. Briefly the principles behind these strategies are as follows:

- **Energy efficiency strategies** are those that either increase the product or service produced per unit energy (component efficiency) or decrease the amount of product or service required (system design). For example automobile design controls its fuel efficiency, while urban design and lifestyles control the number of miles that need to be driven.

- **Carbon intensity strategies** either change the fuels used to generate energy (fuel switching) or prevent the combustion of fuels from resulting in free emission of carbon dioxide to the atmosphere. In the former strategy, fuel switching, one can replace fossil fuels with no carbon fuels (e.g. hydrogen or nuclear), switch to non-fossil carbon based fuels (like biomass), or move from coal to natural gas getting more energy per carbon atom released (low carbon fuels). In the latter, fuel decarbonisation, one can either remove carbon from the fuel before use or capture the carbon dioxide post combustion. In both cases the carbon or carbon dioxide must not only be captured but stored, or sequestered, in a fashion that prevents it from escaping to the atmosphere for a suitable geological period, more than 1000 years. This storage must be accomplished with negative collateral environmental effects.

- **Carbon capture strategies** seek to remove carbon dioxide from the atmosphere by either capturing and storing it through some engineered system or through the process of increasing the rate at which natural parts of the carbon cycle system, forests, oceans or soils, absorb carbon dioxide from the atmosphere. This decreases the net emissions to the atmosphere. This strategy highlights the fact that human activity can also enhance the release of carbon dioxide to the atmosphere through for example poor forest management or soil destruction.

The ultimate carbon management strategy selected by the United States or the rest of the world will not be one of these but a portfolio of options. The options exercised may well vary from country to country. Currently it appears that these portfolios will be driven by an international agreement on the actions individual nations will take. This agreement may take a variety of forms. In their simplest form this might be a timetable of targets for emissions. An example would be an agreement for individual nations to reduce their carbon emissions below 1990 values by 2010.

As one contemplates emission reductions it is important to note that the Framework Convention on Climate Change requires the signatories to take actions which would stabilise carbon dioxide concentrations below "dangerous" levels. While there is continuing debate as to what constitutes dangerous levels, stabilisation represents a significantly more substantive step than is outlined above. In particular, carbon cycle models show that if one wanted to stabilise atmospheric carbon dioxide concentrations at 550 ppm, approximately double the pre-industrial concentration, the total emissions in 2100 would have to be approximately at the same level as 1990. Given the fact of, and desirability of general global development, this emission envelop would have to be achieved in a global economy more than ten times the size of the current one and with a population 50-100% larger than the current population. Simple consideration of the Kaya equation suggests that the technology associated with energy production and use would have to be extremely different and that one might have to consider either the capture of carbon dioxide or direct manipulation of the global carbon cycle to meet the goal.

The magnitude of the change in energy related technology is best understood if one imagines dividing the "allowed" emissions of 2100 equitably among the people of the Earth. This model suggests that the average per capita emission in 2100 could only be 0.5-0.75 tons of carbon per year as compared to the current global value of slightly more than one ton. This should also be compared to the current per capita emissions in the OECD countries, varying between 2 and 5 tons of carbon per capita.

The purpose of the Technology Strategy Project is to gain insight into how technology might evolve in response to the desire to stabilise atmospheric carbon dioxide concentrations. The kind of issues that arise under these circumstances are best understood in the context of a specific example. The following example, developed by Edmonds and his colleagues, illustrates the kinds of issues one has when one moves from forecasting the technologies to forecasting the social and technological issues that develop when one is trying to manipulate the global technological infrastructure to yield a specific environmental outcome.

The approach taken in Kyoto is one of "targets and timetables", by which we mean setting emissions targets and the timetable by which individual nations need to meet those emissions values. Alternatively, an agreement might be framed technologically. The value of this illustration is that it puts the focus on the technology itself, highlighting the insights achieved from consideration of the Kaya equation. A technologically framed agreement, which would stabilise carbon dioxide concentrations at twice pre-industrial values, include all nations, and would minimise economic consequences, thus stranding existing energy generation assets, might look like this:

1. Any new fossil fuel electric power capacity in developed nations installed after the year 2020 must scrub and dispose of the carbon from its exhaust stream.

2. Any new synthetic fuels capacity in developed nations must capture and dispose of carbon released in the conversion process.

3. Beginning in 2050, all new refining capacity in developed nations must remove and sequester carbon from fuels.

4. Imports of carbon-based refinery products by developed nations must be linearly phased out over 50 years beginning in 2020.

5. Participating developing nations must undertake these obligations when their per capita income, measured by purchasing power parity, is equal to the average for developed nations in the year these obligations were first undertaken (2020 and 2050).

An agreement like this has several key features. First, it focuses on existing technology and its evolution to new performance requirements. In particular, it requires a technological pathway that would allow the capture and long term storage of carbon or carbon dioxide from fossil fuel combustion. Second it provides a baseline against which alternate, non-fossil fuel technologies can compete and be priced. Third, it is framed in a way that allows new technology for fossil fuel combustion to be developed that facilitates carbon dioxide scrubbing, for example, and allows that to be introduced at the start of plant lifetime rather than requiring expensive retrofits. Finally, the later implementation of the requirements in the developing world responds to their legitimate need for economic development without initial restraint, and provides a continual motivation for technological innovation.

This vision for providing energy in the future allows continued use of fossil fuels while substantially reducing carbon emissions. To realise this vision it is necessary to develop methods to cost effectively isolate carbon or carbon dioxide, preventing it from being released to the atmosphere. This approach makes it necessary to seriously consider what might be involved in implementing such technologies as:

- Ocean storage of carbon dioxide.

- Terrestrial storage of carbon dioxide.

- Advanced chemical or biological capture and storage of carbon dioxide.

- Storage of carbon.

- Enhancement of natural ocean sinks of carbon dioxide.

- Enhancements of soil uptake of carbon dioxide.

The first four relate to capture of carbon or carbon dioxide from the fossil fuel cycles and the latter two are geo-engineering approaches to carbon storage. If one were pursuing this approach, the four storage technologies probably would need to be pursued in parallel. Currently, it is felt that storage is relatively less expensive than capture technologies, but neither is being employed on a large scale. This however will change as time moves forward and combustion processes are re-engineered to facilitate capture. As the cost of capture comes down storage becomes a greater part of the cost equation. Managing this cost suggests that storage near the point of combustion is advantageous because it reduces transportation cost of the waste carbon. The concept of a single or a few “carbon repositories” is probably not appropriate. Which of the four storage pathways is best matched to any single point combustion or conversion location will vary requiring their parallel development. As the individual technology pathways highlight, it is important to emphasise that there are very clear technological and environmental risks associated with these technologies. The R&D agenda must therefore be very aggressive, if cost-effective technologies are to be in place in time to support the time schedule associated with the technology based agreements such as the one outlined above.

All six require that there be a much deeper and more profound understanding of the carbon cycle, including the effects of elevated carbon dioxide concentrations and carbon-containing biomass in the oceans and deep sub-surface ecosystems. The pursuit of these requires that fundamental research be enhanced in all of these areas. Just as the process of fossil fuel combustion is reversing millions of years of storage of reduced carbon (e.g. oil, gas and coal), the storage technologies attempt to accelerate or augment the natural processes by which carbon dioxide is removed from the atmosphere. The latter two technology pathways, manipulations of the carbon cycle itself, embody even greater risk than the storage pathways.

The risks associated with the technology pathways listed suggest that effective carbon management needs to support alternatives to “burn and sequester”. The eventual path to stabilisation will be a portfolio of technologies, portfolios that will vary from nation to nation. The management of these portfolios will require a systems level analysis of the entire technology portfolio. This analysis methodology, probably based on current integrated assessment approaches to climate change, will be essential for managing the technological research, the economic issues associated with the technology and the penetration of these technologies into practice and into the market. At the next level, these ideas and technologies should have a sound basis in science, both for understanding each technology, and for evaluation of the effectiveness of the technologies in actually ameliorating the atmospheric carbon loading. Thus it is imperative that we have a science-based model of the atmospheric carbon cycle, and that we verify the actual effectiveness of our efforts through measurements. One set of essential elements are models, which are anchored with real measurements, and verification of performance predictions using remote sensing technologies on local, regional, and global scales. The resultant science-based programme will permit us to direct our investments with greater confidence and with improved cost-effectiveness.

Summary and conclusion

In this paper we have described two approaches to technology forecasting as it might apply to the environment. In one case, we can see a forecast in which there was an examination of the emerging environmental concerns coupled with the emerging technologies likely to be applied to address those concerns. The result was a list of ten technologies, which were felt to have a likely impact on consumer products in the next decade. These technologies ranged from agrogenetics, the direct manipulations of plant genomes to improve environmental performance of agriculture, to lightweight vehicles. The list included not only consumer products themselves, but also the constituent technology behind the improvement of the environmental performance of consumer products.

In the other case we have described the underlying issues associated with another kind of environmental technology forecast. In this case, the problem is one of achieving a long-term environmental objective, the stabilisation of the concentration of atmospheric carbon dioxide. In this case the technology forecasting moves to the development of what is required to generate an entirely new technological future. This future needs not only to achieve the desirable environmental goal, but to do so in a way that is globally equitable, economically viable and does not create yet another generation of global environmental problems just as thorny and difficult as the prospect of anthropogenic climate change.

TECHNOLOGY OPTIONS FOR SUSTAINABLE DEVELOPMENT

by

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In the Netherlands technology foresight activities play an important role in targeting science and technology towards present and future societal needs. This paper describes a recent environmental technology foresight study, explicitly meant to re-align technological development with the long-term goal of achieving sustainable development. The foresight was meant – and is actually used – to develop a policy strategy for stimulating those technological systems that might radically increase the environmental efficiency of products, processes and services.

Introduction

Science and technology policy is one of the most dynamic policy domains in the Netherlands. The strong political interest in science and technology reflects a wide recognition of the relevance of scientific research and technological development in relation to industrial competitiveness and societal problems. In preparing for the challenges our country faces in the 21st Century, research and development are regarded as vital, whether they concern ageing, transportation and mobility issues or sustainable development.

Although the importance of science and technology is recognised, it is far from evident that scientific research and technological development are attuned to societal needs. Traditionally, science and technology policy in most industrialised countries focused mainly on the supply side of the innovation process, hardly taking the societal needs into account. However, during the last five years, stimulated forcefully by the government report "Knowledge in transition" (1995), the focus of Dutch science and technology policy is to strengthen the interaction between the supply of and demand for knowledge. The Dutch Ministry of Housing, Physical Planning and the Environment has attempted to gain an understanding of the possibilities technology presents to reduce current environmental problems.

Evidently there are a large number of technological options that could contribute to economic growth and ecological sustainability. However, encouraging technological development is no guarantee of environmental improvement. For example, new technology can lead to new forms of pollution. In other words: technology implies threats as well as opportunities. A policy on technology from the viewpoint of sustainable development should serve to strengthen the opportunities where possible and mitigate any threats.

Recently the Ministry of the Environment commissioned TNO (Netherlands Organisation for Applied Scientific Research) to perform a technology foresight study that was explicitly meant to re-align technological development with the long-term goal of achieving sustainable development. The objective of this foresight was to find handles for policy aiming to selectively stimulate technological systems, with the intention of increasing the environmental efficiency of products, processes and activities.

The concept of "environmental efficiency" is a key concept in Dutch environmental policy. It refers to a societal development in which economic growth, an increase in competitive strengths and employment goes hand in hand with a decrease in the pressure on the environment and the use of non-renewable raw materials. Technological development is regarded as one of the key elements in realising radical improvements in environmental efficiency.

This environment-oriented foresight study focuses on a period of 15 to 25 years for the purpose of including more radical innovations within the scope of study. One important notion is that it is meaningful to obtain an understanding of the environmental effects of new technological systems in advance of the implementation. The opportunity to intervene early on in the development trajectory may have greater effect on the eventual technology. Also it seems better to identify potential undesired side effects of new technologies, in order to prevent them from occurring.

Methodology

A systems approach

An important new element in this technology foresight study is that we did not focus on separate technologies, but took a systems approach to technological development. Also, we combined a broadly-based inventory of the technological supply with an analysis of dynamism in society's demand.

This technological foresight study takes a very wide field into consideration. It is impossible to describe the technological developments in detail. And more importantly, a detailed analysis of technological components would overlook the relation between these components: it is only in combination that they perform their specific function (transportation, communication). Therefore, the study focuses on the identification and analysis of developments at system level. The notion of "technological system" was introduced for the combination of technical means and the human skills and knowledge to make these means perform a specific, societal function.

The study focuses on technological systems which might possibly be used in the Netherlands over the next 15 to 25 years. When assessing the environmental relevance of these systems we made a distinction in terms of the sphere of application for which they are developed. We chose a breakdown into societal functions. This, far more than a classification into branches of industry, provided us with the opportunity to do justice to the social dynamism over the next few decades. These functions will not change quickly; the way in which these functions are fulfilled will.

The term "societal function" is seen in the broad sense. It covers the function fulfilment for the end consumer, as well as for the industrial suppliers. The different functions are based on Michael Porter's often-used categories of economic goods and services[4]. In analogy with Porter's classification, a distinction is made between:

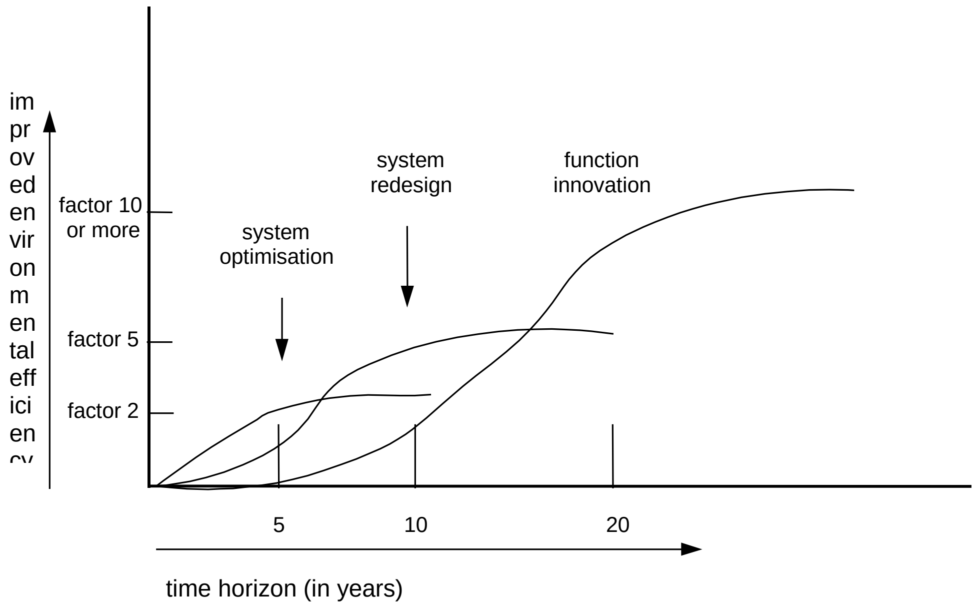
- Generic functions that feed all the other functions, such as the supply of energy and (raw) materials.

- Intermediate functions that create the essential conditions for all other functions, such as movement (transport and infrastructure), communication and business services.

- End-use functions that fulfil the needs of the consumer, namely: nourishment; housing, care and recreation.

If we focus on innovation processes at the system level, we should distinguish between innovation taken one step at a time and radical innovation. Step-by-step innovation is based on existing systems; radical innovation often focuses on new systems to replace existing ones. We make a distinction here between three ideal kinds of innovation: optimisation, redesign and function innovation of technological systems.

Figure 1. Three kinds of environment-oriented system innovations



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

Optimisation focuses on improving existing products, processes or infrastructure. The main concern here is to modify systems which already have a commercial use. In this type of improvement, the system concept is not essentially modified but the efficiency of the system is increased by making slight modifications only.

In the second kind of innovation, redesign, the actual design of existing products, processes or infrastructure is partly changed. Specific features of the system are changed, for instance by choosing to use materials that can be made suitable for reuse in the disposal stage. In redesign, the system concept remains largely unchanged.

More far-reaching improvements can be achieved by departing from the system concept and by developing new systems which perform the same function better. This can result in a radical change as to how the function is fulfilled. This kind of innovation is called function-oriented innovation or in short: *function innovation*.

Optimisation, redesign and function innovation are indicative of ideal types within a continuum. The degree of freedom in this continuum becomes progressively higher. Whereas for optimisation the system concept is in essence still a given factor, for function innovation only the system's function is important. In many cases, function innovation is linked with shifts in the associated socio-economic system. This is because new parties enter the market and established market positions come under pressure. In addition to the required R&D effort, it is because of this socio-economic dimension that function innovations need considerably more time to be realised than optimisation of existing systems. This is illustrated in Figure 1.

Figure 1 also shows that the difference between these different kinds of innovation is important from the viewpoint of the environment. Improving existing systems can lead to substantial improvements in efficiency, but at some point, the existing concept becomes fully developed and the ceiling will have been reached in terms of environmental efficiency. Only by changing the design, or by introducing a completely new system concept would it become possible to break through this ceiling. In the long run a greater leap in efficiency may be expected from the development of new systems than from optimising existing ones. How great that leap will be obviously depends on the system and the function. Figure 1 only gives a general indication in this respect.

Two routes

In terms of methodology, two routes were followed in the environmental technology foresight “81 Options”:

- Mapping out the technological developments that could lead to a significant change in environmental impact in the next 15 to 25 years (positive, or negative).

- Investigating the main societal driving forces which are decisive for the resulting developments.

First an overview was compiled of all the currently known technological developments which over the next 15 to 20 years could lead to a substantial reduction in today's environmental problems or, conversely, to the advent of new environmental problems. This overview was based on the findings of numerous technology foresight studies describing future trends and expectations in a wide variety of technological fields.

Subsequently, a systematic assessment was made of the potential consequences of adopting new or upgraded technological systems in terms of changes in environmental efficiency (both positive and negative) in relation to the dominant systems in the year 1997. Extent of changes in the consumption of energy, scarce raw materials and in the release of emissions and waste were analysed when making this assessment. Also the use of space was taken into account. All changes were assessed on the basis of unit of output (product or service), implying that any potential developments in production volume or amount of consumption were not taken into account. Nor were behavioural changes, which could either increase or neutralise the environmental pay-off of improvements in environmental efficiency taken into consideration when carrying out this assessment.

The second route consisted of a scenario analysis of the main societal driving forces and obstacles that are decisive for the rate and direction of technological development, and thus determine how fast new technological systems penetrate the market. On the one hand, the specific features of the systems themselves, such as the technological barriers that need to be overcome before a system becomes ripe for the market, were taken into consideration. On the other hand, the driving forces and obstacles of a cultural, social and economic nature were also analysed. Among other things this relates to the pace of economic growth, the interaction between the societal demand and the technological supply, society's acceptance of technological innovation and the price we are prepared to pay for resolving collective problems. These analyses were based on future scenarios drawn up by the Netherlands Central Planning Bureau (see Table 1). The resulting information on driving forces and obstacles was used to identify handles for policy.

Table 1: Relevant differences between the Central Planning Bureau scenarios (for the Netherlands)

Balanced Growth	European Renaissance	Global shift
• dominant market perspective is balanced perspective • open market correction	• dominant market perspective is co-ordination perspective • forming of trade blocs	• dominant market perspective is open market perspective • trade liberalisation
• strong economic growth • strong growth in labour and capital resources productivity (A,K) and material productivity (M)	• strong economic growth • strong growth in material productivity (M) and extra stimuli for economic infrastructure (G)	• economic growth lags behind • growth in labour and capital resources productivity (A,K)
• ample willingness to change • substantial R&D • strong technological dynamism	• less call for innovation • substantial R&D • less strong technological dynamism	• conservative, more of the same • little R&D • innovation coming to a halt, duplication
• global awareness of the environment • high level of energy saving	• European awareness of the environment • energy saving	• local awareness of the environment • very little saving of energy

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

Results

Five major clusters of technological systems

The inventory of the technological systems that could lead to a substantial change of the environmental impact over the next 15 to 25 years resulted in a list of 81 technological systems. These systems can be categorised in five major clusters:

– Energy systems, including systems based on coal gasification, solar energy, wind energy, biomass, hydrogen, nuclear fusion, nuclear fission and innovations in energy distribution (for both local and mobile supplies).

– New (raw) materials, particularly biological raw materials, composites and new colour systems.

– Production systems, geared towards optimising industrial production (including the metal industry, synthetic materials production industry, food processing industry) and agricultural production.

– Information and communication systems, relating mainly to the application of information and communication technology in the industrial and service sectors, as well as in the domestic environment.

– Transport systems, a cluster of innovative systems for the transportation of people and goods (e.g. super-aircraft, zeppelins, new trains, hybrid transport and underground pipeline transport). In these innovations, the introduction of new or improved modalities is inevitably coupled with changes in the transport infrastructure.

Technological innovation predominantly improves environmental efficiency

Technological innovation leads predominantly to an improvement in the environmental efficiency of products, processes and activities. Approximately 60 of the 81 systems can be expected to result in an improvement in environmental efficiency. Of these we can expect a positive contribution in the form of:

- Substitution: substitution of oil, gas and coal by renewable energy sources, including the utilisation of energy systems based on biomass, solar and wind energy.
- Energy saving: a reduction in energy consumption per unit of output that can be expected in the majority of industrial production systems.
- A reduction in combustion emissions (CO_2, SO_x and NO_x) and (waste) clinkers inherent in the utilisation of oil, gas and coal.
- Dematerialization: a reduction in the input of scarce materials (metals, groundwater and tap water) per unit of output that can be expected from industrial production systems on the basis of closing the cycle.
- Waste reduction: a reduction of hazardous and non-hazardous waste per unit of output, particularly through using the majority of the production systems investigated.

Considerable saving on energy consumption and the use of materials, as well as a substantial reduction in emissions and waste can be achieved by optimising the technological systems of today. About 60% of all systems are in this category. Even larger efficiency improvements can be realised either by radically changing the design of contemporary technological systems or by developing new systems to take over the functions of existing systems in a completely new way. Only few identified systems are in this category.

Several innovations also have adverse impacts

The findings of the technology foresight also stress that technological innovation is no guarantee of environmental improvement. This is evident in about 20 of the 81 systems. These, in addition to the positive effects, also can be expected to result in adverse effects on the environmental efficiency of products, processes and activities. They relate mainly to:

- A potential increase in the consumption of oil, gas and/or coal and the resulting combustion emissions and (waste) clinkers, for instance through the introduction of supersonic aircraft.
- A potential increase in waste and the utilisation of scarce raw materials (especially metals) which could result from implementing the information and communication systems investigated.
- A potential increase of emissions linked with intensive farming (mainly manure and crop protection agents) resulting from the cultivation of agricultural crops to be used as biological raw material for the energy supply and agricultural chemistry, etc.
- The possible generation of new, complex waste streams which are at present difficult to process, for instance from using metallic-matrix-composites and nuclear fission.

It is important that the detection of these potential effects in this technology foresight study is followed up by more specific initiatives focusing on identifying preventive solutions in the design stage.

In addition to these adverse consequences, a number of technological systems could shift existing environmental problems onto the use of space. It concerns particularly those systems for the functions of supplying energy and (raw) materials and the function of movement. One concrete example in this respect is the substitution of oil by biomass in energy supply and in the chemical industry. Clearly, the production of agricultural crops demands that physical space is available. Another example is in the field of transportation. Some of the new systems for the environmentally-efficient transport of persons and goods require the construction of infrastructural facilities and, hence, additional physical space. Throughout Europe, but particularly in the Netherlands, physical space of good quality is rapidly becoming a scarce resource. It is urgent that these shifts onto physical space be investigated further.

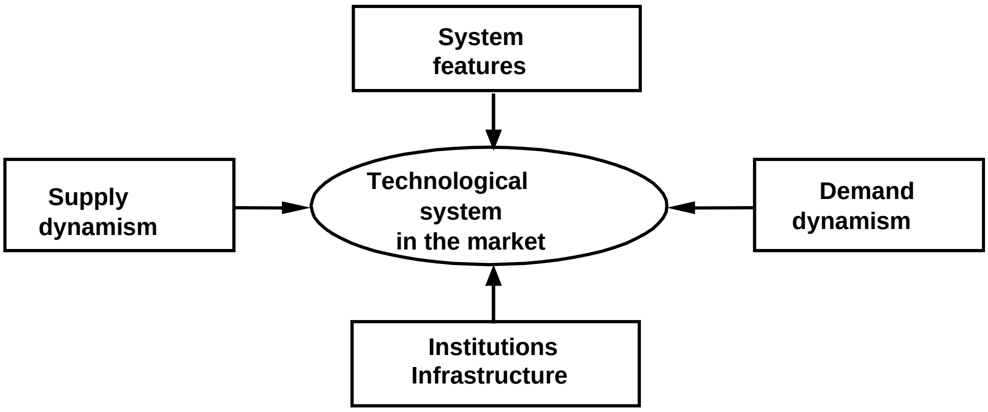
Driving forces and obstacles

The observation that the majority of environmentally-relevant systems examined here contribute in a positive sense towards environmental efficiency may not lead to the expectation that technological innovation will lead, in due course, to the automatic solving of all environmental problems. Such a conclusion would overlook any possible adverse effects of several technological systems. Moreover, it does not go without saying that the environmentally efficient systems will automatically break though into society.

How quickly a new system reaches the market expansion stage, and how extensive that expansion is before the market reaches saturation point, depends on a number of driving forces and obstacles which accelerate or hinder market development. Figure 2 illustrates that such driving forces and obstacles are found in the characteristics of:

- The technological system itself (technical features, unwelcome characteristics).
- The market parties that develop and market the system (the supply side).
- The market parties that can use the system (the demand side).
- Current governmental policy (infrastructure, regulations).

Figure 2. Obstacles and driving forces associated with societal breakthrough



Source: Weterings *et al* (1997).

It is the actual characteristics of a technological system that conceal the scientific and technological obstacles or thresholds that will need to be overcome before the system can be realised. The size of these obstacles determines how much money will be required for research and development in order to get a new system ready for commercial production. It is obvious that research and development will still continue, leading to updated variations of the system (which also will be marketed eventually).

How quickly a new system reaches the expansion stage, and how extensive that expansion is before the market reaches saturation point, depends on driving forces and obstacles of a cultural, social and economic nature. Among other things this relates to the economic dynamism: the rate of economic growth, the level of prosperity and the interaction between demand pull and technology push. The social and cultural dynamism of society is expressed in society's acceptance of technological innovation and the price people are prepared to pay to resolve societal problems.

For each of the five clusters of technological systems mentioned above, an analysis was made of the main societal trends and driving forces stimulating or hampering the process of innovation and diffusion. When assessing the 81 environmentally-relevant systems in three contrasting future scenarios we observed that the development and use of environmentally-relevant technological systems was just as dependent on societal trends (the demand side) as on the continued augmentation of knowledge (the supply side).

Especially the price of energy and the willingness of society to change its habits are apparently of crucial significance. The price of oil, gas and coal is evidently the main obstacle standing in the way of environmentally-efficient technological systems. This applies not only with regard to innovations in the field of energy supplies, but also to innovations in industrial production systems and transport systems.

From foresight towards policy

Handles for policy

The government is brought into contact with new technological systems at an early stage via standardisation, product regulations and other instruments which set a framework for the workings of market mechanisms. In addition to this regulatory role, the government also fulfils a role in developing both the supply (R&D investments, subsidies) and the demand (price measures, subsidies, the government as a demand party).

As we found in our foresight, the price of fossil energy carriers is evidently by far the most significant obstacle to the development and breakthrough of environmentally-efficient technological systems. This applies not only with regard to innovations in the energy supply, but also to innovations in industrial production systems and transport systems. In theory, a price increase on fossil energy carriers (e.g. by introducing an energy tax) would make a positive contribution to environment-oriented technological innovation. In connection with energy systems, industrial production systems and transport systems, we recommend investigating which forms are conceivable and what potential consequences can be expected from government measures which focus on lowering this price barrier.

However, it is not only the energy price that offers a handle for the selective stimulation of environmentally-efficient systems. The most important driving forces for the breakthrough of environmentally-efficient systems are: a high level of economical dynamism (supply) and an articulated societal demand for (environmentally) efficient systems (demand). This environment-oriented technology foresight study shows that the government could additionally promote the breakthrough of more environmentally-efficient systems by:

1. Encouraging the supply dynamism of technology development, for instance by initiating dialogues with the parties involved, stimulation of combined public and private R&D investments and by facilitating knowledge transfer between companies.

2. Encouraging a selective articulation of the demand, for instance by the government taking action as the pro-active party on the market, and by introducing price measures which selectively lower the threshold for introducing new systems.

3. Direct government control, geared towards intervening in the development of technological systems which could lead to adverse environmental effects, for instance by means of environmental regulations which impose more stringent requirements on existing systems, plus a selective policy on the introduction of new systems.

Although it might be tempting to focus on selective incentives policy, it is important not to limit those incentives to too great an extent to a few technological options. A substantial contribution towards the aim of achieving sustainable development can especially be expected from a policy that stimulates the supply dynamism and the demand articulation, in combination with monitoring both the direction and pace of environmentally-relevant technological innovation.

Coping with uncertainty

An important policy issue is also how to cope with the substantial lack of knowledge regarding the economical, societal and environmental impact of new technologies. It is impossible to identify and assess all relevant developments over a period of 15 to 25 years from now, the time horizon of this foresight study.

Indeed, the result of this technology foresight draws attention to the considerable lack of knowledge on the impact of new technologies. Especially in the field of information and communication technology, the speed of technological development is so fast that all the potential uses are yet unknown. This is more important, since the continuing penetration of information and communication technology is a significant trend in all future scenarios. These ICT systems may contribute to substantial changes in all social functions. The further growth of products and services based on information and communication technology is expected to expand enormously. Considerable impact is expected on industrial production and business services. The added value of the provision of services *vis-à-vis* physical production gradually becomes more important. The office environment shrinks to the dimension of the individual: all white collar workers are provided with portable data and communication equipment. In addition a large growth in the market for virtual amusement can be expected. Citizens are entertained by new services such as virtual travel in both time and space, experiencing these new opportunities as a substitute for the need for physical movement. An extra stimulus to develop information and communication systems may arise from investments in a European traffic and transport infrastructure.

So far, research into information and communication technology applications has been mainly supply-driven. Little can be said as to how the information and communication technology revolution will influence other functions over the next few decades, or the associated substitution effects. Nor are the direct environmental impacts of the revolutionary growth in information and communication technology undisputed. On the one hand we may expect that the penetration of information and communication technology will lead to an increase in the use of energy and scarce raw materials in connection with the production and use of information and communication technology hardware. On the other hand, miniaturisation will raise the energy and material efficiency of the equipment. While some people expect that information and communication systems will reverse the current growth in the use of paper and transport movements, others point out that the opposite is quite conceivable.

The lack of insight into the potential environmental effects of information and communication systems has become acute since it is widely expected that these systems will penetrate strongly into society over the next few decades. A deeper foresight study into the potential environmental effects of information and communication systems in the different areas of application is needed. Such a study should provide a greater understanding of the conditions that underlie these effects, as well as insight into any preventive measures that can be taken.

Ongoing initiatives

The findings of the environmental technology foresight have given new impulses to policy development in the Netherlands. For instance, in the governmental white paper on Environment and Economy, several technological systems were described as “inspiring imaginary projects”. In the recent National Environmental Policy Plan III the systems approach has found a profound place in the policy on environmental technology. The findings also gave rise to enhance the budget for an existing research-programme on Economy, Ecology and Technology (EET). New policy instruments, such as task forces and a first mover facility were announced. Also a decision has been taken for a study to explore the possibilities of ICT for a sustainable economy. The basic notion of these policy instruments is that changes in technological systems go hand in hand with changes in socio-economic systems. The instruments are used to create incentives in the socio-economic system that support the actual implementation of new technological systems.

A direct follow-up of the Environmental Technology Foresight study was a more detailed study, with the objective to define more specific policy action plans for nine technological systems. Dialogue is a key characteristic in the follow-up. The results form a basis on which a dialogue between key actors from both research and industry can be started. The objective is to establish a shared vision of how to direct the technological development towards a sustainable economy. Dialogue is to be started with policy makers from all relevant Dutch ministries and with key actors from relevant Dutch research organisations and stakeholders from industry.

This last element, the active participation of relevant stakeholders, is directly related to the experiences with technology foresight and technology policy in the Netherlands. Dutch policy makers pay more and more attention to the innovation system itself: the institutions, the level and dynamic nature of their co-operation, their positioning in (inter)national networks. New networks are identified, combining relevant research organisations, industries and stakeholders, in order to identify and develop new options in collaboration. The most recent example is the start of the National Initiative for Sustainable Development (NIDO). This initiative has the objective to bring together different stakeholders around sustainable technological development. Here also technological systems are the focus. The NIDO, together with the relevant actors, identifies new sustainable technological systems. The NIDO also stimulates and facilitates research around the driving forces and barriers relevant to technological and institutional breakthroughs.

Conclusions

The main conclusion of the Technology Foresight Study is that technology offers opportunities for sustainable development. But alignment of technological developments with sustainability is necessary. Secondary effects like shifting the burden from environment to space should be countered. Also more attention is needed for system innovations.

The government is an important player on different levels (regulation, stakeholder) and should start the dialogue with relevant parties. The system approach and societal needs offer a useful conceptual framework to bring parties together. The Environmental Technology foresight study could form a basis for this dialogue.

NOTES

1. Ministry of Housing, Spatial Planning and the Environment, Postbox 30945, 2600 GX The Hague (The Netherlands). E-mail: Vollenbroek@DSP.DGM.minvrom.nl

2. TNO Environmental Sciences, Energy Research and Process Innovation, P.O. Box 342, 7300 AH Apeldoorn (The Netherlands). E-mail: r.weterings@mep.tno.nl

3. TNO Centre for Strategy, Technology and Policy, P.O. Box 6030, 260 JA Delft (The Netherlands). E-mail: Butter@stb.tno.nl

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POST FORESIGHT IMPLEMENTATION IN THE UNITED KINGDOM

by

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Abstract

The first stage of UK Foresight identified environmentally sustainable technologies as a key area "so promising that further work was absolutely necessary". The scope of sustainable technology is wide, including techniques and management issues as well as technologies, and ranging from cleaner products and processes to end-of-pipe solutions. Because of this range across many disciplines and all branches of industry, "sustainable technologies" can appear diffuse and unfocused. It is therefore an important challenge to raise the profile of sustainable technologies and promote them to all sectors. The UK Foresight's success is as a process, engaging industry, researchers and government in a continuing dialogue and partnership to identify opportunities, stimulate interest and catalyse action for R&D and commercialisation. There have been three elements to implementing Foresight for sustainable technologies. The first was to bring together the existing key players from government, industry and the research community to get them to work together and identify some key opportunities as a basis for stimulating debate. The second element was to raise the profile by engaging the public support of the chief executives and chairmen of some of the major UK companies; and also to provide some research funding for joint university/industry projects. The third element has been to spread the word by challenging other Foresight Panels with an "environmental futures" package, providing guidance for companies to do their own internal foresight exercise, and by working with industry groups and organisations (Confederation of British Industry, trade associations etc.) to undertake group foresight exercises based on the identified opportunities for sustainable technologies, by widely circulating the documents on opportunities for formal comment from a wide range of bodies and by publishing the results and activities of Foresight for Sustainable Technologies on the Web.

Introduction

The UK Foresight exercise was launched in 1994. Its aim is to improve the competitiveness of the UK economy and enhance the quality of life – thus recognising that wealth creation includes economic, social and environmental dimensions. It attempts to look at future market opportunities and needs 15 to 20 years ahead and to identify what has to be done in terms of research and development and other activities to ensure that the United Kingdom can respond to the opportunities and challenges.

The programme is driven forward by 16 independent panels which cover all aspects of economic activity – from agriculture to transport, chemicals to communications. Each Panel consists of individuals from the academic research community, industry, non-governmental organisations and government. In December 1995 a "Natural Resources and Environment Panel" was established – of which the "Cleaner Technologies and Processes Sub-panel" is a part; in common with all the other panels this sub-panel includes researchers, industrialists, civil servants and individuals from non-governmental organisations.

First stage of foresight

The first step of the whole Foresight exercise was to gain an assessment of the most important challenges and opportunities both nationally and globally and to identify the United Kingdom’s strengths and weaknesses in relation to these. Two methods were used for this. The first was a very large Delphi exercise. The second was a series of national and regional meetings held by each panel to stimulate debate and get a wide qualitative input. In the event it seems that the second exercise was the most fruitful. The results of this work were used by each of the panels to draw up a report on the key issues, research opportunities and broad recommendations for the United Kingdom.

These initial findings and recommendations of each of the 16 panels were reviewed by the overall Foresight Steering Group to identify generic priorities in science and technology. The Steering group recognised “Environmentally sustainable technology” as one of the key areas “so promising that further work was absolutely vital” and recommended it for “particularly urgent attention by organisations in the public and private sectors”. The Cleaner Technologies and Processes Sub-panel took this recommendation as its main remit. This paper discusses the experience which the sub-panel has had in implementing the recommendation.

Sustainable technologies

The Cleaner Technologies and Processes Sub-panel is concerned with the complete range of technologies, techniques, products and processes that will enable humankind to reduce the impact of production and consumption on the environment and to establish a more sustainable mode of development. It therefore identifies a very wide range of needs and opportunities ranging from management approaches to technological developments, from end-of-pipe solutions to integrated processes and new, cleaner products and services, and from the issues of production and resource use to the questions of consumption and consumer behaviour.

Opportunities for the application and development of sustainable technologies and cleaner technologies and process are, by definition, to be found across all industry branches and sectors of economic activity. This breadth presents a wide field of opportunity but also poses difficulties in ensuring a focus for attention.

The policy challenge for sustainable technologies

There has always been a dilemma as to how best to deal with environmental technologies in science policy. On the one hand, environmental issues should be integrated within each sector. But there is the danger that individual industry branches or traditional disciplines will not accord it much or any priority. On the other hand, if it is kept in its own programme, then other areas of work can justify ignoring it on the basis that it is being dealt with elsewhere.

The focus for R&D in sustainable technologies is difficult to identify partly because it is newly emerging and partly because it is diffused through many industries, sectors and disciplines. By its nature the work is cross-sectoral as environmental considerations become integrated into many aspects of the economy. Inter-sectoral and inter-disciplinary work is never easy. It is difficult to focus, it does not have strong institutions to support it and is not easily addressed through traditional structures such as trade bodies, learned and professional societies or traditional university departments.

This therefore was precisely the challenge for the Cleaner Technologies and Processes Sub-panel:

- To focus attention, resources and effort on R&D for environmentally sustainable technologies and techniques.
- To develop linkages and institutional support for the opportunities.
- To challenge all sectors with the environmental issues and opportunities, promote integration and encourage relevant work in a wide range of disciplines and sectors.
- To spread the word about these opportunities and challenges across a wide range of the industrial and research communities both public and private.

Foresight is about process

It is worth noting at this stage that Foresight is about process and not prediction. This is for two reasons. Firstly, it is exceedingly difficult to predict the future and hence to select priorities from the list of important R&D opportunities and challenges. Secondly, in the context of UK science and technology policy, there is a major emphasis on joint public-private research and much public funding is dependent upon private sector matched funding or involvement.

The United Kingdom has always had a relatively strong and successful science and research base. It is its failure to build on this and develop ideas through to widespread application and commercialisation that is of concern. This informs much of current UK science policy and the Foresight exercise itself. Thus as well as the academic will and interest to carry forward new areas there must be also be a private sector, one might say entrepreneurial, interest in developing aspects which can be taken through to commercial or other widespread application. It is these different interests, working together, who will decide which areas they jointly want to pursue; rather than some top down direction.

The success of Foresight has been that it has stimulated the process of bringing together the different parties to research, development and commercialisation so that they can have a closer dialogue and consider together the opportunities and challenges of the longer term.

Strategy for implementing Foresight

Given this context and the challenge for environmentally sustainable technologies outlined above, the Cleaner Technologies and Processes Sub-panel adopted a strategy for implementing Foresight which had three elements:

- Engaging the interest groups.
- Raising the profile.
- Spreading the word (getting beyond the R&D director).

Each of these three aspects is now discussed in turn.

Engaging the interest groups

The interest groups include academic researchers, industry, government and non-governmental organisations. Individuals from each of these groups were brought together to form the sub-panel: to meet regularly and debate the scope and range of opportunities. The aim was to set out the broad research agenda for the future as a basis for more detailed work, to stimulate debate and the thinking of individuals or groups so that they could begin to articulate areas they wanted to work on. The main written output of this activity was a document setting out the full scope of research and development opportunities in response to environmental sustainability: “Sustainable Technologies for a Cleaner World; A Key Priority and a Major Opportunity”. This has within it an opportunities matrix which shows in broad terms the key research needs and the geographical areas of the world where the outputs of such research might be applied. (The matrix is appended to this paper). It forms the basis of an executive summary which has been circulated widely to chief executives and others throughout the country to raise awareness of the opportunities and draw them into the process.

Of course one of the problems of environmental sustainability is that the range of R&D requirements and opportunities is very broad; no single researcher or organisation is interested in them all. Therefore a series of focus groups was set up to take forward particular areas in more detail. These groups are set up at the request of those who want to take areas forward. Like most of the work of Foresight, panels attendance and contribution to the work of the panels and focus groups is all on a voluntary, unpaid basis. Thus only those with a real interest in taking areas forward are likely to participate.

As already pointed out, Foresight is about process. The focus groups are an important part of that process. They bring together parties from the research and from the business community (including in some cases the investment community) who have a common interest in a particular area of work. This enables them to meet (so providing the opportunity for partnerships to form) and to begin to map out a common agenda for future work areas. This common agenda will inform individual plans. Where partnerships form it helps to underpin joint work. In addition, by making the common agenda publicly available to a wider audience, it helps to stimulate more detailed debate amongst those who were not able to be part of the focus group.

Focus groups have been working together in the following fields:

- Water management.
- Sensors and instrumentation.
- Waste management.
- Air pollution reduction from stationary sources.
- Cleaner product design.
- Information and communications technologies for sustainable development.
- Decision-making methods for sustainable development.
- Urban development in developing countries.

The material produced by these groups is made available in both hard copy and on the Foresight Web site.

Raising the profile

There are three ways in which the profile of opportunities from R&D in environmentally sustainable technologies has been raised and championed. One aimed at business leaders, a second at joint academic/industry research and the third at other Foresight panels to ensure that they integrate environmental sustainability into their work.

A national conference on " Sustainable Technologies for a Cleaner World" was held primarily for senior business people. The day was opened and closed with speeches from government ministers outlining the public policy approach. The core of the day was made of presentations from chief executives and others from well known and major UK companies discussing what they were already doing in terms of R&D and commercial response to the global opportunities and challenges of environmental sustainability. This was, therefore, not a traditional research or academic conference but one which attracted those who might invest in the development and commercialisation of new approaches, products and technologies. The reports of the sub-panel and the focus groups formed an important background to the debate.

There is nothing like the availability of finance to raise the profile of an area. Under the Foresight initiative there are limited research funds available. The latest Foresight Challenge Fund included calls for research projects which were to develop technologies for a cleaner world. These funds were only available to joint academic/business bids and required some matching private sector funding. Like all R&D funds they were competitive. The UK Department of Trade and Industry is currently considering the establishment of a "Sustainable Technologies Initiative" which may further support development of these types of technologies.

As pointed out previously, one challenge for the development of sustainable technologies is to get all sectors of research and branches of industry to begin to integrate the concepts into their developments. Therefore, to stimulate this process, meetings were held with representatives of the other panels in Foresight which covered the full range of industrial and economic activity. They were also engaged in a formal seminar process to identify the key challenges and impacts of sustainability on their areas of work.

Given that Foresight takes a long-term perspective (15 to 20 years) it was recognised that pure prediction was out of the question. It was also clear that the issue of environmental sustainability was a factor in the deliberations of many of the other panels. Therefore the Environment and Natural Resources Panel and the Cleaner Technologies Sub-panel set up a series of scenarios of different futures based upon a number of dimensions including environmental, governance and market factors. These scenarios were then used to "challenge" other panels and government departments and made available to others so that they could see how their views of future needs and opportunities stood up to some of the potential future environmental and other problems.

Spreading the word

The main objective has been to spread the word to an audience beyond those who are normally engaged in the debates about future R&D. This is in two respects, getting the message of the opportunities and need for research into the board rooms and strategy directors of large firms (and not just the R&D functions of firms); and taking the agenda to companies who are not normally engaged in R&D to any great extent. There has also been the supplementary aspect of raising the profile of this type of inter-disciplinary work amongst traditional academic groups.

Clearly the profile raising activities of the conference and to a lesser extent, the debates with the other panels will have had a useful effect. In particular the high profile of the chief executives speaking at the conference has meant that the message has been heard by other senior business leaders. In addition the written material (including the proceedings of the conference) has been widely circulated (through mailing to members of trade and business associations, and to members of learned/professional societies). They have also been made available on the Web.

However, to have a more specific impact three approaches have been adopted.

The individual documents with their research agendas have been formally circulated to various industry and research bodies; with a request for a formal response. Thus ensuring that the debate is placed on the agenda of these bodies.

Secondly, the work of the sub-panel and focus groups has been presented by members of the groups at a variety of different professional, academic and trade conferences and seminars. To supplement this, group members in professional journals have published short papers and articles.

Thirdly, the Foresight initiative produced a teaching pack and guide to help small and medium-sized enterprises (SMEs) to do their own futures and foresight work. This has been combined with the sustainable technology research agenda developed by the sub-panel and focus groups to provide material for relevant branches of industry. In a number of regions this has been used by regional industry bodies or regional technology transfer agencies to engage the local SMEs with sustainable technology R&D opportunities.

Conclusions

This approach to implementing Foresight has been heavily influenced by the UK context; the concern that the country has a poor track record of developing and commercialising basic research. This has led to a position where much research has to find at least partial support from the private sector. It also recognises that in the end it is largely the private sector that will have to take the initiative in investing in and commercialising results. Hence the overall approach of involving all of the partners and the emphasis on the process of participation, dialogue and meeting rather than on any forecast of "critical technologies". Given the long-term aspirations of the UK Foresight and the undoubted barriers to innovation, it will take some time for it be clear just how effective the process has been in the aggregate. However, the individual activities outlined above have clearly drawn in a wider range of participants than normally take part in these debates. They have also managed to help raise the profile of environmentally sustainable technologies quite considerably.

ANNEX

OPPORTUNITIES MATRIX

There are a wide range of opportunities and needs for sustainable technologies. Clearly different technologies, techniques and products are appropriate for different markets. The "opportunities matrix" presented here shows in broad-brush terms where the major demand and markets are likely to emerge although of course many of the technologies and services will have world-wide application. The matrix highlights the significance of export markets.

EXAMPLES OF RESEARCH AREAS AND POTENTIAL MARKET APPLICATION

Main Technology Area	*Developed Countries*	*Newly Industrialising and East/Central Europe*	*Developing Countries*
❑ "Cleaner" Processes & Products	• Process manufacturing improvements to reduce materials, energy, water and waste • Waste minimisation from design to disposal, water recycling in use • Separation technologies, energy efficiency processes and machines material substitutes, IT and control • Biotech processes to replace Chemical and some physical processes (basic biotech application)	• Cleaner/more efficient heavy engineering, bulk chemicals processes	
❑ New Products/Service Concepts	• Recyclable/demountable/ upgradeable products • `Shared" ownership/leasing/lifetime care concepts • Cradle to grave/lifetime responsibility • Product development methods (a combination of IT, materials application and management/design • Low energy use products, low water use etc		
❑ Associated Socio-Economic Research/ Management Research	• "Life style" research – impact of sustainability on consumption patterns – "back casting"/scenario building to identify constraints – identifying "clean growth" paths • "Models of reduced energy/materials intensive growth • Public decision methods, social choice • Studies to understand how to stimulate innovation, manufacturing flexibility, new product/process design, acceptance and take-up • Trade/products standards/emissions link		

EXAMPLES OF RESEARCH AREAS AND POTENTIAL MARKET APPLICATION (continued/...)

Main Technology Area	*Developed Countries*	*Newly Industrialising and East/Central Europe*	*Developing Countries*
❑ Environmental Technologies/Techniques - pollution control; - clean-up	• Environmental monitors/sensors (biosensors, robust sensors, relate instrumentation, remote operation and reporting/data collection, systems analysis) • Waste water treatment, water remediation, water treatment (separation in process use: ground water remediation, desalination, recycling contract) • Waste management and treatment (waste tracking/IT systems, hazardous waste disposal) Waste separation and pre-treatment technologies • Waste minimisation *Others* • Other associated technologies - land remediation; - air pollution control • VOC/Odour control		
❑ Water Technologies	• Ground water clean-up - bioremediation • Water reuse/recycling in domestic/commercial use (better separation materials, biotech, robust control & monitoring) • Less water intensive production/process methods, increased industrial recycling (membranes/separation) • Less water intensive agricultural practices (climate forecasting, low dose application)		• Desalination (better separation) • Salt resistant/drought tolerant crops • Small scale/self contained/modular water/wastewater treatment plant • Robust monitoring and control
❑ Management Public Policy Tools	• Charging/taxing techniques • Service Management • Risk and cost/benefit assessment • State/Pressure/Response modelling		

EXAMPLES OF RESEARCH AREAS AND POTENTIAL MARKET APPLICATION (continued/...)

Main Technology Area	*Developed Countries*	*Newly Industrialising and East/Central Europe*	*Developing Countries*
❑ Energy - Energy efficiency in use - Energy reduction in use - Sustainable energy generation	• Energy efficient consumer products • New forms of energy generation - PVs - biomass - wind - solar thermal • Cleaner coal combustion • Energy efficient production methods • Energy storage - batteries; - fuel cells	• Smaller localised energy systems for large cities • Improved fossil fuel/energy efficiency • Carbon sequestration • Fuel source conversion and cleaner burn technologies	• Appropriate technology buildings • Small scale, domestic biomass stove • PV applications for dispersed/domestic and water use
❑ Agriculture	• Soil quality maintenance • Reduce water use • Nitrogen fixing improved		
❑ Transport - Vehicles - Power Sources - Infrastructure - Multi-Modal - Reducing Demand	• Vehicle materials weight reduction • Vehicle materials increased recyclability (materials R&D) • Power system - non carbon based:- - electric/fuel cell - hydrogen • Power systems more efficient:- - hybrid • Integrated systems/road/transport information and control • More efficient use of existing infrastructure • New forms of car ownership - leasing, sharing, car pooling etc.		
❑ Construction and Urban Infrastructure - Less Energy Intensive	• "Smart" building and construction materials	• Materials substitution in buildings • Low "incorporated" energy in building materials/products • Non-centralised and non energy intensive services infrastructure (water, sewage, energy) • Less energy use through design and planning	
❑ Materials Substitution:- - Lighter Materials - Miniaturisation (lighter/ stronger) - Non hazardous materials	• Focus on replacements for hazardous materials (materials, biotech, chemicals research) • Light weight/strong and recyclable materials		

Source: Office of Science and Technology, Foresight: Sustainable Technologies for a Cleaner World - A Key Priority and a Major Opportunity, DTI (1998).

RECENT INDUSTRY TRENDS IN RELATION TO TECHNOLOGY POLICY DEVELOPMENT

by

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N.B. The views expressed in this document do not reflect the position of the European Commission but are entirely based on the opinion of the author.

The implementation of integrated technology concepts aiming at reducing the use of toxic materials and improving material productivity is becoming increasingly more widespread. Moreover, several surveys among institutional investors and industrialists have shown that sustainable development with its three dimensions -- environment, social, economic -- is playing a role in entrepreneurial decision making processes. On the other hand, several national initiatives, the Amsterdam treaty of the EU, and also the economy, finance and trade ministers of the OECD (annual meeting on 28-29 April 1998) now endorse sustainable development according to the Brundtland definition as a principal policy objective. With respect to the environmental dimension of sustainable development and the contribution by industry, i.e. the enhanced implementation of clean and resource efficient technology concepts, new complexities at the regulatory level arise. The integration of environmental factors into policies being a declared goal, many practices of developing such a strategy and the information on which they are based, i.e. technology foresight exercises, do not fully embrace integrated views and fall therefore short of meeting the policy objectives. There are currently several interesting trends occurring in industry that are integrating environmental factors in a bottom up way and that could be turned into levers of technology policy if they were sufficiently recognised and addressed by policies and in the design of foresight exercises.

The goal of this paper is to give an overview of recent trends in the way in which different industry branches deal with environmental problems. We thereby touch upon the issue of the potential and the limitations of industry's power to contribute to cleaner and environmentally sound production. This overview, although necessarily incomplete, sheds light on industry's behaviour in view of changing policy objectives and points to policy requirements.

Introduction

Originally the main emphasis of the environmental debate, policy and practice was on limiting the release of toxic materials into the air, water and soil. Regulations addressed this issue by prescribing limit values and norms that prompted industry to fit filters, catalytic converters, etc. onto existing equipment. Over the years, a whole new branch of industry emerged: environmental technology, most of which is represented by these so-called add-on or end-of-pipe technologies. Despite their positive effects - making air and water cleaner - add-on technology has not been without its critics from industry, policy makers and environmentalists. The devices are expensive for a company and often do not really solve an environmental problem, but rather shift the disposal of a pollutant from one medium to another. Hence, environment was seen by industry as a nuisance and a costly factor to a company.

Parallel to the diffusion and implementation of end-of-pipe technologies (which still continue) the environmental debate has shifted to more complex issues such as: resource depletion, waste reduction, bio-diversity, global climate change. Industry's response, partly on a pro-active basis and partly complying with new legislation, has been to implement technologies with a different objective: rather than limiting emissions at the end of the process the new focus is on reducing resource use and limiting the utilisation of toxic substances along the life cycle of a product. These approaches are commonly and loosely referred to as integrated, or clean technologies.

This can be achieved in several different ways: closing material flows inside and outside of the company, better logistics, improved energy efficiency, redesigning production processes and products, better process control, substituting raw materials, use of fewer toxic chemicals and using new technologies. The clean technology issue is not just about radical innovation and functional changes. There is already a vast body of empirical evidence which shows that marginal process and product design modifications can bring about significant reductions in the use of materials and the quantity of pollution, whilst improving the competitiveness of the firm (for many instructive examples see DeSimone & Popoff, 1997). Closer inspection shows that the integration of resource-saving measures in the production process is to a considerable degree an organisational challenge and a result of good stewardship rather than being entirely a technical problem.

Parallel to the recognition that environmentally compatible production processes and products can increase a firm's competitiveness, industry developed a large number of tools that aimed at integrating environmental factors into a business decision procedures (see for example, Blumberg *et al.* 1996).

Despite this undeniable progress, the environmental situation deteriorates as excessive land use and resource depletion continue. This raises the question as to whether the complex political frameworks that govern regulation are appropriate for coping with the current challenge of sustainable development in general and to put forward solutions for addressing environmental problems in a way that is viable for industry in particular. Although technology may be part of the solution, it is also clear that achieving environmental progress is not entirely a technological problem, but rather a problem of life style and the use of technology. Our current attitude towards technology being dominated by a technology fix paradigm is also clearly epitomised by technology foresight exercises which aim at appreciating technology development from a technology supply view angle. Technology policy programmes that are being developed in turn are also dominated by a technology push and supply point of view.

This imbalance is increasingly being recognised by politicians, policy makers, managers, engineers and consumers. The endorsement of sustainable development in the Amsterdam Treaty of the European Union, the integration of environmental aspects into all EU policies after the Cardiff Summit at European level, several initiatives at national level as well as many business attempts to attend to environmental factors as drivers of business activity are instructive examples. Yet, we are currently in an experimental phase. There is growing concern about environmental problems and increasing perception that simple solutions are not at hand. With respect to technology foresight processes, one may ask whether these exercises would not better meet societal needs by having a more balanced proportion of technology supply and demand view angles. Moreover, these exercises could be used in order to facilitate the policy making process.

There are currently a large number of trends and the emergence of new concepts and perceptions in industry that are suitable for such an approach. This paper looks at some of these trends and concepts. Due to space restrictions we limit ourselves here to less-known practices. Hence, we will concentrate on the image of a firm to the public, the products-to-services issue and recent developments in the financial services. Several of these developments can hardly be called a trend today, at best a weak signal. In addition, many developments are so recent that no scientific literature exists on these issues to date. As a consequence, we shall use references to newspapers and news services. Finally, we want to put these developments into a broader context. In particular, these recent ways of dealing with environmental problems are interesting and important, because they go beyond pure engineering solutions. They rather take environment into account as part of more general concepts including an increased perception of industry's responsibility for societal concerns. Also, industry is discovering environment as a business driver rather than a cost factor through the enhanced competitiveness of a firm that is more resource productive and that has a better image with respect to its stakeholders and clients.

The image of a firm

A closer look at the motivations that lead companies to implement cleaner technologies reveals several interesting factors. The first and most important factor still is cost. Clean technologies (covering the vast spectrum of approaches and initiatives described above) can be cost saving due to the reduced consumption of resources, reduced costs for safety, cleaning and remediation, etc. These are all factors that have a direct impact on the bottom line of a company. Besides cost, other factors play an important role as well. Many companies that see themselves as being concerned and committed to environment and sustainable development underline their social responsibility (BATE News Service, April 1998, 5-7; Schmidheiny *et al.* 1997). Another factor is the public image that a firm has. Today, a company can less and less afford to have a negative image. An increasing number of firms are issuing environmental performance reports which give a more or less detailed account of their efforts to reduce their environmental impact. A recent survey in Germany **(**Fichter *et al.* 1995**)** came to the conclusion that the quality and design of the reports are still quite heterogeneous. Moreover, information is difficult to verify. Companies are trying to respond to these criticisms by designing their reports according to broad based national or international standards, such as those by the United Nations Environmental Programme (UNEP), the Coalition for Environmentally Responsible Economics (CERES). It can be expected that the quality and the design of environmental reports will improve as a result of this standardisation. Purchasers and customers on the other hand can exert pressure by requiring high quality environmental reports and thereby reinforce this trend.

Firms are also increasingly integrating environmental factors into several departments and levels of decision making by the adoption of environmental management systems (EMS). Besides the application of schemes developed by the firm itself, an increasing number of firms adopt standardised EMS's such as the ISO 14000 series or EMAS. These standards use a management system approach rather than prescribing specific environmental performance levels such as emission values or energy consumption standards. Many firms hope their customers appreciate the adoption of such schemes and use eco-auditing in their advertisement, including environmental or annual reports. One important aspect of EMAS is that it requires audited companies to produce a public statement after the audit. This often sparks a debate, because companies that did not pass the audit may feel negative publicity despite their efforts. Moreover, the standards are criticised because they may encourage firms to conformance with the set rules instead of developing their own EMS.

In contrast to bigger firms, especially multinationals, SMEs often do not have the resources to develop their own EMS. Consequently, more standardised approaches, such as ISO 14000, EMAS or approaches based on commercial software packages which help managers to systematically and interactively integrate environmental factors into evaluation and decision procedures are more practical for them. Nevertheless, there are also big firms that prefer to rely on standardised solutions and that ask to be audited under ISO 14000 or EMAS.

To get an idea of how many companies are certified to date it is instructive to compare the leading country, the United Kingdom, with 650 certifications with France, No. 10 on the world list, with 64 certifications (BATE's ISO 14000 Update, 1998).

Besides customers, shareholders also ask for environmental details about a company's performance and management. There is a growing perception among industrial agents, raters in banks and investment portfolio managers that companies with a good environmental record and environmental management systems in place are on the whole better managed than other firms. A recent survey among institutional investors has shown that around two-thirds rate environmental factors as important for improving a company's competitiveness (*BATE news service*, April 1998, p. 7; see also the section on "The Financial Community" hereafter, for more details).

Visibility of a firm's environmental performance cannot only be reached by environmental reporting, but also by a company's daily contact with its customers. The overnight shipping company UPS has been testing a two-way reusable shipping envelope and uses paperboard packages with a high level of post-consumer recycled content. The project resulted from a collaboration with the Alliance for Environmental Innovation, in which other shipping companies such as the US Postal Service, Airborne, Federal Express and DHL are engaged. The reason why UPS decided to improve on the environmental record of packaging is its high visibility (*BATE News Service*, April 1998, pp. 8-9).

Besides environmental reporting and environmental management systems, firms try to document their environmental position by voluntarily joining a group of companies agreeing on a set of principles such as the Responsible Care (reg. TM), an initiative of national chemical companies, or the International Chamber of Commerce Business Charter for Sustainable Development, (1990), the Keidanren Global Environment Charter in 1991, the Keidanren Appeal on the Environment in 1996 or the World Business Council for Sustainable Development. These and many more do not only aim at documenting a firm's environmental attitude, but they also show that there is an increased perception of the public's concerns by companies.

The shift towards transparency and commitments reflects not only an increasing concern about environment by the business world but also a general societal trend towards shared participation and responsibility.

Governments have a large number of tools and instruments to enhance and foster the trends in relation to a company's wish to have a good public image with respect to environmental performance. The examples given above range from pure PR activities in informing the public, to approaches in which the company itself has a direct impact on the bottom line through its improved environmental performance. In fact, most initiatives share several of these facets. It is therefore unlikely that a single one could be deemed the supreme way to be selected and supported by governmental action. It is more likely that a mixture of several approaches will be more successful. There is a unique chance for governmental action, as both sides, consumers as well as industry, are converging towards a common objective.

From products to services

The reduction of pollution and resource use in relation to products and goods produced in industrial processes cannot only be achieved by closing material flows but also by redesigning the product's function. System innovations focusing on the optimisation of the performance of a good, leading to the replacement of a purchasable good by a service, are accompanied by a large decrease of material consumption on the one hand, and economic gains on the other. There is an increasing trend pro-active firms to replace products by services, as other advantages for the firm come with this, such as increased customer loyalty and reduced marketing costs. A strategic advantage is hidden in the fact that services include sufficiency and efficiency solutions, whereas products are limited to efficiency approaches (Giarini & Stahel, 1993). Customers appreciate services, because they give them flexibility, cost guarantee, low risk exposure and zero fixed capital. Recently, there have also been several legislative acts responding to this emerging trend.

Besides many relatively well known initiatives by young entrepreneurs to found new companies that provide new services, it is considerably less well known that also several multinational companies have already successfully implemented these new strategies, de-coupling turn-over and profits from resource consumption and manufacturing volume. Schindler elevators is selling carefree vertical transport instead of elevators; Xerox is offering custom-made reproduction service instead of selling photocopiers; Safety-Kleen and Dow Europe sell the services of chemicals instead of selling chemicals; Safechem and Dow Germany are renting solvents to dry cleansers; Mobil Oil is selling engine oil quality monitoring instead of engine oil (for its "Mobil 1" synthetic oils); GE Capital and ILFC lease aircraft and Interface Inc. nylon carpets. The concept is considered by many others, including Electrolux and Braun, the Swedish and German household appliance manufacturers. A great number of companies already practice a voluntary buy-back or free take-back system, such as Eastman Kodak and Fuji for their single-use cameras, or GE Medical Systems for medical equipment by any manufacturer.

Providing services is not necessarily more environmentally friendly than selling products. However, in most of these cases, the product used to perform the service remains the property of the service company and it is taken back after use and cleaned or remanufactured, before it can be used again. For the company there is a financial incentive to increase the lifetime of the product delivering the service, as for example photocopiers in the case of Rank Xerox or solvents in the case of Safechem and Dow Germany. The rental of artificial hearts by Baxter and the NASA space shuttle have put to rest the idea that the re-use of long-life goods means second-rate quality or safety, and old-fashioned technology. Interestingly, one success factor is partly a regionalisation of the activities, skill pools and responsibilities of a company.

Providing services is often accompanied by out-sourcing company functions and it is rapidly becoming a generally accepted form of selling results instead of (capital) goods or services. Textile leasing is a strategy that is becoming the norm for uniforms and professional work clothing, hotel linen, hospital textiles (even in sterile operating theatres) and towels in up-market lavatories. In a recent agreement between the car manufacturer Ford UK and DuPont, the car painting operation was outsourced to DuPont, which now sells painted cars rather than gallons of paint. DuPont now has an interest to reduce resource use and has simultaneously increased the share of operations with Ford from 50% to 100% (*BATE news service*, April 1998, p. 2). Another example is United Parcels Service, which plans to overtake entire logistics planning and operations for companies.

Rethinking products as services is clearly becoming a trend. It is less noted than spectacular technological breakthroughs, but there are many important indicators that it is happening, e.g. increasing guarantees. Some car manufacturers offer a total cost guarantee over three or five years, which includes all costs except tyre wear and fuel. Electric cars in California are for rent only. Industry also shows an increasing willingness to accept unlimited product responsibility, money-back guarantees, exchange offers and other forms of voluntary product take-back. And at the political framework level, e.g. the EU-Directives on product liability, and more recently on product safety, and the draft directive on service liability, all stipulate a ten year liability period. However, despite these developments, most manufacturers still give a short term warranty (six or 12 months).

The products to services issue is largely unnoticed in various technology foresight exercises. This is mostly due to the fact that services such as the ones described here are not so much about new technologies, but rather an issue of using technologies. As a consequence, services which are not being identified by a predominantly technology supply view angle in foresight exercises are not taken into consideration. While obligations to increase the number of take back facilities, longer product liabilities etc are good initiatives to give stimuli for more resource efficient products, a considerable number of services are not included. While too much regulation could be detrimental to a fruitful evolution of the entire spectrum of services, there will inevitably be more regulation on a mid-term horizon, in particular in order to create a level playing field for the markets. The progress towards resource efficient services on a large scale depends to a considerable degree on an integrated technology policy view. Balancing technology demand and supply in foresight exercises will be a prerequisite for an increased rate of replacing resource intensive products by resource efficient services and the creation of legal framework conditions which allow these services to prosper.

The financial community

Replacing resource intensive technologies by more resource efficient ones requires investments; not particularly unplanned investments or more investments: sooner or later companies will replace their older technologies by more recent ones. Hence, investments will be made anyway. Once they have been made, however, the new technology will not be replaced so quickly. Turnover times vary considerably from one technology sector to the other. Hence, unless a considerable progress in resource productivity is achieved, an investment can be considered sunk costs from the environmental point of view. A key question in this issue therefore is how the huge amounts of money spent every year for investments into technology could be invested in a way that environment would benefit most (see e.g. Schmidtheiny and Zorraquin, 1996).

This investment problem is important in most OECD countries as many technologies have led to quasi lock-in situations in which it is easier to add on to existing technology paths and structures thereby reinforcing the lock-in rather than overcoming it. For developing countries the problem is even more urgent as they have many possible routes to go today. Once, however, investments are made which create the same quasi lock-in states as in the industrialised countries, developing countries may find it even more difficult to change the course, as they have created a technology dependence from which they cannot escape more easily than industrialised countries can do today. Hence, precious time may be lost and irreversible environmental damage may occur.

Our following discussion on the role of financial services is applicable to a certain extent to both, industrialised countries and developing countries. However, we will primarily concentrate on the current situation in the United States and Europe.

While most companies in the production sector were confronted with environmental regulations and its effects already in the ’70s, the financial industry, i.e., banks and insurance companies, were the last business sector that was confronted with and reacted to environmental challenges. Banks and insurers recognised quickly that environmental risk is often financial risk, both in casualty insurance and in the investment portfolios, and – as a consequence – that environmental risk can be transformed into financial opportunity, provided it is dealt with proactively. In addition, there is significant scope for influencing the environmental behaviour of suppliers and customers. Although the financial sectors became involved in the debate on sustainable development only relatively lately, their activities belong now to the most advanced in the whole private sector. The financial sector does not play an important role in technology foresight exercises, however. As a consequence, its role in technology policy has been limited so far. As will be shown by the following discussion, the way in which the financial sector has been able to integrate environmental factors as a business driver that penetrates deeply into other industrial sectors could play an important role for an integrated technology policy.

The financial sector’s contribution results primarily from three different levers: the concept/perception of lender liability, a company’s environmental performance in relation to investors and the strategy chosen by insurance companies to cope with the potential threat due to the effects of global climate change. Policy responses to amplify the impact of these three levers can be found at least at the level of political framework conditions in the case of lender liability and investments and at the level of facilitation between different stakeholders in the case of insurance companies strategy to meet global warming.

Lender liability: Mainstream market responses in relation to environmental factors occurred in the 1980s, when credit banks and insurers started to integrate the risks of contaminated sites into their assessment procedures for real estate lending or liability insurance. Their main motivation was to react to legal developments which posed a direct potential risk to their own business. In particular, liability for cleanup of contaminated sites is imposed on the owner under the US Comprehensive Environmental Response, Compensation and Liability Act of 1980 (this regulation is known as “Superfund”). Although Superfund exempts lenders, e.g. banks as owners, there have been many cases where courts ruled that banks were held liable for polluted sites in which they had stakes (see e.g., Schmidheiny & Zorraquin, 1996). As a consequence, banks discovered a new term: lender liability. While this specific regulation exists in the United States, it had also an impact on European banks acting as lenders to US firms. Today, a considerable proportion of total losses of banks occur in relation to contaminated sites that were given to the banks as financial security. Consequently, financial institutions are now including environmental checks regularly into their decision making in those countries that either have the appropriate legal framework, e.g. the United States, or where banks want to pro-actively anticipate potential regulations. The following examples show accumulating empirical evidence for this trend. In a recent National Wildlife Federation Global Survey of the financial service sector, half of the respondents indicated that financial markets have started to place greater emphasis on environmental screens in their commercial credit decisions (Ganzi & Tanner, 1997). A recent joint study by the RAND Corporation and the Harvard School of Public Health found that firms named as potentially responsible parties at multiple "national priority" Superfund sites had capital costs about three-tenths of a percentage point higher than they otherwise would have been (Garber & Hammit, 1998). In Europe, the legal situation is still heterogeneous and the liability issue ranges over the full scale from the one extreme where the State takes responsibility and pays for maintenance, clean up and follow up of polluted sites, to liability that remains with the owner.

The experience made in relation to lender liability shows that shifting political framework conditions such that it is unattractive to be involved in environmentally unfriendly activities may have a deep and sustainable impact on lending and investment behaviour, thereby creating market conditions for cleaner technologies that are widely believed to be non-existent on average in industrialised countries.

Investments: “(...) Although the body supporting the proposition that better environmental management adds to share holder value is not large, a growing body of work suggests that companies which rate highly on environmental criteria also provide better-than-average returns to shareholders, and that financial analysts and investors can improve their investment performance by attending to environmental value drivers (...)” (Blumberg *et al.*, 1996).

In fact, there is accumulating empirical evidence for a growing perception among industrial agents, raters in banks and investment portfolio managers that companies with a good environmental record and environmental management systems in place are on the whole better managed than other firms. A recent survey among institutional investors has shown that around two-thirds of the respondents say sustainable development applies to corporate strategy; nearly 70% use it, in varying degrees, in their evaluation of companies for investment. Roughly one half said that companies do not provide adequate information on the subject. And about one third of the respondents expect that environment will become much more important in the future. In the environment section of the questionnaire, 79% of the respondents considered environment important in evaluation (*BATE news service*, April 1998, p.7). The examples of stock market responses discussed above are also applicable here. Moreover, there is a recent example, where a single incident had a tremendous impact onto the stock market value of a company. The toxic sludge spill over of Swedish-Canadian mining company Boliden in Andalucia, Spain, and its severe consequences for the near-by natural reserve Donana led to a USD 138, stock value drop (*BATE News Service*, June 1998, p.3).

Besides significant responses at the level of main stream financial activities, there are also new products offered by financial institutions, namely so called screened eco-efficiency funds. Companies that are included in the portfolio do not necessarily represent environmental technology firms (e.g. wind energy suppliers) but represent "normal" companies that are rated above average on a list of factors that are centred around the concept of eco-efficiency: increased energy efficiency, increased material productivity, reduction of use of chemicals with global warming potential, reduction of use of ozone layer depleting chemicals, reduction of toxic emissions, quality of environmental management, water use and environmental liabilities. The weighting applied to each criterion is different from industry to industry, but is consistent within an industry. Several companies having stakes in nuclear industry or genetically modified organisms are excluded from these portfolios. The composition of these funds is clearly different from so-called ethical or green funds, where specific firms, e.g. manufacturers of environmental technology or renewable energy producers are pooled. The fact that eco-efficient portfolios include "traditional firms" has also led to critiques. For a survey of the strategy of the funds, the companies included and the criteria used see Brand (1997), for a more investment oriented analysis Maurer & Johner (1997).

Although the eco-efficient funds are still small and almost insignificant compared to the volume of other funds of big banks, they are highly rated. For example, the SBC Eco-Performance Fund launched in summer 1997 performed right from the beginning better than the MSCI World Index, which is used for comparison. As Baumgartner (1997) mentioned, this was one of the first proofs that environmentally oriented investments can yield market typical return on investment. Also other funds have provided above average return and stability. However, it is yet too early for general conclusions. In general, investment funds are rated on a longer time scale, typically five years, using several weighting and performance criteria, whereby the recent past receives more weighting. In the last couple of years there have been an increasing number of banks and insurance companies, particularly in Switzerland and Norway, that launched eco-efficient funds. Besides this, similar products start to be offered in other countries also. In North America, where one can find a large spectrum of investment products based on ethical and "green" criteria, funds using indicator-based screening are rare. Only recently the first two eco-efficiency funds were launched in Canada (*BATE News Service*, September 1998, pp. 2-4). Despite their small number so far, this type of investment product is expected to become an important trend. A lot of the most sophisticated rating scheme developments that link environmental with economic performance occur in relation to these funds.

These trends are primarily driven by a growing environmental awareness among investors, whether on environmental or on economical grounds. Technology policy could develop towards a more balanced structure with respect to demand and supply aspects of technology development by enhancing these trends among investors. One way in which this could be done is by focusing on political frameworks which make it gradually more attractive to behave in an environmentally friendly way as the financial markets respond rapidly and companies start to use environment as a business driver.

The insurance industry and global climate change: With respect to global warming insurance companies have taken an interesting position which differs in several respects from that adopted by many others involved in that issue: namely, one takes action although there is no proof that (human behaviour induced) global warming is really happening. There can be no doubt: the insurance industry takes the climate issue very seriously. The main reason for adopting a precautionary approach with respect to climate change is that once it has started it is almost impossible to stop and the impacts on the insurance industry can be dramatic. It does not only effect the property insurance companies through damages caused by floods and storms. Life insurers will be effected through heatwaves and their health impacts, e.g. diseases which have not occurred in certain areas before, such as malaria.

Climate change is a very complex problem for insurance companies as there is a very broad risk distribution with no direct causal relation between the risk, the behaviour of the insurance taker and the level of the premium the insurance company determines. As there is no single supreme strategy, insurance companies fight on many fronts. One of the steps taken by insurers (besides the more general ones presented above and which also apply to global change) is to fund climate change and weather forecast research. Rather than increasing premiums of house owners, insurance companies believe it is vital to identify key hazards and to educate property stake holders in risk-avoiding strategies. With respect to companies and sectors that consume a lot of energy or produce/use greenhouse gases the exclusion principle is out of fashion. One rather tries to promote the implementation of more energy efficient solutions etc. using amongst others screened eco-efficient investment portfolio management. Finally, it is important for the insurance industry to create a voice to influence policy makers and to lobby for emission control.

In conclusion, the strategies chosen by insurers are characterised by prudent behaviour. One tries to avoid at any price losing customers who might get better tariffs with unscrupulous and less forward-looking and less concerned companies.

While the political action required in relation to investments is framework conditions that foster the emerging market responses, the case of the insurance companies’ attitude to deal with global climate change is different. Here, the role of governments would be to act as a facilitator to foster growing trends that are fed by the increasing demand for shared participation and responsibility. The case of the insurance industry is perhaps the first perceptible business response that calls for a societal consensus.

Conclusion

Compared to the often highly polarised image that industry has to live with (being the creators of wealth and labour on the one hand, while being the bad polluters on the other hand), the picture that one gets from companies implementing clean technologies, shifting from products to services, or companies that implement EMS schemes and carry out LCA, looks considerably more positive. It is true that there are an increasing number of companies which discover that environment can be an important driver to increase competitiveness. Indeed, there are the famous success stories of eco-efficient approaches realised by companies such as Dow Chemicals, 3M, Rank Xerox and many others. However, the success stories apply to parts of the company, sometimes only parts of a product or a production line, and it may take many years before a big multinational company has replaced old processes by more eco-efficient ones. One reason is that it is sometimes very difficult to find a cost-effective and environmentally sound solution among many possibilities. Moreover, sometimes environmentally friendly solutions can only be realised in synchrony with suppliers, which makes the task even more difficult. While there is a huge potential in big firms, SMEs often neither have the resources nor the know-how to realise environmentally friendly solutions (Eder & Fresner, 1998). Environmental innovation in companies can be very profitable, but this is not necessarily the case. The process of the so-called “Greening of Industry” may be a silent revolution but it is also a long learning process in which companies develop tools and concepts that are both environmentally friendly and economically profitable. This is not meant to diminish the achievements at all. The managers, engineers and technicians of pro-active firms have to be clearly considered pioneers of the post-industrial era.

Most of the success stories of e.g. clean technologies represent the smaller part, mostly very innovative firms, of the whole industry community and these pro-active firms represent one side of the coin. The other side is that there are still many companies for which compliance with environmental legislation determines their way of dealing with environmental issues, and there are also still the big polluters. Therefore, one has to be careful with general judgements and conclusions. On a scale of 200 years of industrialisation, industry is just starting to change behaviour leading to a substantial contribution to reducing environmental impact. The success of creating and implementing efficient regulatory frameworks will depend on not taking away the thrust of the innovative firms and at the same time help to pull less developed ones into an environmentally friendly mainstream.

The large number of emerging trends in the way in which industry is integrating environment into business procedures on the one hand, and the large number of companies that adopt the compliance strategy on the other hand, show that there is enough fertile ground for more integrated political frameworks that can enhance the trends presented and reward forerunners and drive less advanced industry. The examples presented of business trends are all based on a perception of responsibility for societal concerns or on discovering environment as a business driver. Moreover, they are hardly about new technology, but rather about the use of technology. All examples show an integrated approach towards environment of the companies involved. Hence, a technology policy that does not embrace such an integrated perspective is likely not to address the levers that are currently developing. Hence, the need for more balanced technology push/supply and demand view angles in technology foresight exercises.

It is neither the task of industry, nor could industrial agents be the sole drivers or have the exclusive responsibility for achieving sustainable development in the environmental dimension. This is exemplified in two recent scenario building exercises (WBCSD, 1998; Hammond, 1998). These and other exercises typically present a variety of development options. In most cases, entirely market based scenarios in which short-term profit maximisation reigns, lead to unsustainable futures. More positive futures often are based on shared participation, alliance building including consumers and social values. This again corroborates what has been said concerning the call for a technology policy that is based less on the technology fix paradigm.

While a younger generation of managers and engineers which have different values including environmental and social ones may gradually replace an older and less concerned generation, it will also remain true that business is built on money. It will therefore be difficult to make considerable progress towards better environment solely on the basis of competing values. Recognising that environmental factors have the potential to become driving factors for industry may eventually lead to a situation of plurality of values, leading on average to environmental benefit.

We are currently witnessing the first phase of integrating environmental factors into business accounting, evaluation and decision procedures. The integration of environmental factors is now also taking place in many local, regional, national and supranational administrations (e.g. the EU Commission). After that, even more integrated business strategies and policy concepts, such as integrated product management and planning and foresight exercises based on societal needs rather than solely technology push criteria based ones will be necessary. Although there are several national and also supra-national initiatives to drastically reduce material flows and land use, it is unlikely that the current policies can solve the dichotomy of becoming more resource efficient on the one hand, and consuming ever more resources on the other. The current steps and initiatives being taken are steps into the right direction. However, they are only the first necessary steps to be taken.

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TECHNOLOGY FORESIGHT AND SUSTAINABLE DEVELOPMENT USING A SCENARIO APPROACH

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Summary

We know that continued innovation would be required to realise the ambition of sustainable development and meet the needs of current and future generations in an environmentally sound manner. Since new and improved technologies are likely to contribute substantially to that process of innovation, and given the commercial opportunities and risks involved, there is obvious interest in understanding which choices will be compatible with greater sustainability. To make such an assessment requires insight into developments in technology, which a foresight process can provide, but also involves considering other uncertainties such as the public's attitudes to technology, its response to technology-based innovation, constraints imposed by existing infrastructures, and financing issues and market behaviour.

This paper considers the use of scenario planning techniques to broaden the context within which to think about the results of technology foresight exercises, such as those being sponsored by several national governments. We briefly describe three scenarios for sustainable development to illustrate how these can highlight uncertainties and challenge perceptions of the social and economic environments within which sustainable development must be achieved. We then suggest a way of using these to identify policy frameworks and innovation management processes that can most effectively realise the potential of the technologies identified by foresight.

Sustainable development and the WBCSD

The World Business Council for Sustainable Development (WBCSD) is an organisation of some 125 member companies sharing a commitment to the principles of sustainable development. Its members are a diverse group of companies drawn from a wide range of business sectors and based in many countries around the world. The WBCSD provides these members with a forum to explore the business role in sustainable development, and it works with people and organisations outside the business community to broaden its and their perspectives and to identify possible ways to address the issues that are raised.

Different people interpret "Sustainable Development" in different ways, but the definition usually refers to a desire for greater equity, quality of life and environmental well being today and for future generations. The social and economic pillars of sustainability are as important as the environmental pillar, and all three are interdependent. A society that is weak in one respect easily lacks the means to address the others.

People also have different views of what a sustainable world will look like, but there seems to be no doubt that achieving the required high standards of care will involve continued innovation across a broad front.

Some, even perhaps a large part, of this innovation will involve technology, both as a tool for greater efficiency and, more importantly, as a resource generator that gives people the means to change and improve the way they live.

Among the contributions that business can make to sustainable development, it is likely to remain the primary conduit for innovation and for introducing new, clean technologies to produce (and recycle) goods and provide services. Its other contributions include providing employment, generating wealth and acting in a socially responsible manner where it operates. These contributions interact with each other, and there are inevitable compromises to be managed, for example when developments in technology or changes in demand for products require periodic changes in employment patterns.

Taking these points together, a business that is committed to the principles of sustainable development has a keen interest in understanding how it can most effectively manage its innovation processes to support this commitment. One aspect of this is to be able to recognise what are the most appropriate technological choices to make.

Attitudes to innovation and technology

For most of this century, there has been a widespread belief in the power of science and technology to support progress and drive innovation. Since it is unthinkable (in the developed nations at least) that we could either step back or sustain our current standards of living without the underpinning and resource creating capacity of science and technology, it seems to have been a well founded belief.

There is no reason to suppose that we are close to the limits of what technology can provide, although from the Schumpeterian perspective[1], a new wave of technologies is poised to become the dominant agent of change. Many believe that the era we are entering into will be characterised by a profound capacity to monitor, manipulate and manage our immediate environments by using smart systems based on information, microelectronic, bio- and advanced materials technologies.

Such possibilities raise mixed emotions. For the positivists, the opportunities to build a cleaner, better world seem enormous. For others, science has lost its magic. Technological developments have measurable side effects, which they feel are unacceptable.

Gray[2] has described the situation very well, noting the profound paradox inherent in technology development that it is both the source and the remedy of environmental change. Grübler[3] puts it another way, professing that only technology can liberate the natural environment from the consequences of human interference.

In the process of creating a more affluent (and healthier) society, the public perception of what is an acceptable risk has evolved. People can seem to discount the capacity of technology and engineering skill to obviate this risk, but it is important to realise that objective risk is not a meaningful concept in this context[4]. Furthermore, the issue also goes into matters of conviction, for example about what is undue interference with nature, or into a debate about the whole nature of western lifestyles. Fundamentally, this boils down to understanding what we mean by progress. The danger is that this discussion becomes so polarised that it becomes impossible to find a consensual way forward.

Another concern is that not everyone is gaining the benefits that technology might offer them. Technology itself amplifies this concern, since the communications revolution brings the plight of disadvantaged nations and people home to us all. But underneath, there are alternative views of technology, as materiel to be given to (or withheld from) those who need it, or as tools used by those who have acquired the necessary skills. The former view emphasises the importance of technology transfer, whereas the latter emphasises the need to raise standards as a whole, to secure the complete package of social and economic progress that technology can underpin.

As we have noted earlier, technology-led innovation is a process that happens mainly through businesses operating within the market, even though its effects may go much further. If only for this reason, the consequences of these conflicting perspectives need to be understood (and ways found to deal with them) in the broad social and economic context within which such markets operate. Social and economic factors (including perceptions of environmental impact) influence which scientific avenues are explored. Innovation creates new opportunities by linking the resulting technical capabilities with human aspirations and needs. The market determines which of these capabilities will be widely adopted and at what rate. And the public mood will move on, in the process influencing what is taught and what is believed to be important.

To give a simple example, we might determine that technology offers the most effective way to deal with the challenge of climate change, by enabling a step change in energy efficiency and by providing carbon-free sources and carriers of energy. Achieving this would require some new approaches and some (but probably not too much) new basic science. No doubt we can delineate the gaps, then apply the resources and intellectual capacity that will eventually fill these gaps.

However, a blunt "technology-push" approach would almost certainly introduce unanticipated burdens and side effects, which the public is likely to consider unacceptable: we would have ignored basic principles of ethics[5]. More prosaically, the consumer may not like the resulting products and services, so they will fail to sell. Alternatively, the products may be incompatible with existing infrastructures and it may be felt uneconomic to write off and replace the assets these infrastructures represent.

None of this is to deny the importance of science and technology as key fundamental enablers of change, or to ignore the consensus that exists in the scientific community about promising emerging technologies. The problem is that identifying these technologies does not help us to anticipate the manner and rate at which they will be implemented outside the laboratory, taken up in the marketplace and so contribute to the process of innovation.

This is an emotive subject, yet critical if we are to address the challenges of sustainable development successfully. Kaku wrote his popular book[6] *Visions: how science will revolutionise the 21st century*, based on interviews with about 100 well-known scientists, including several Nobel laureates, because of his surprise that all too often an eccentric social critic's individual prejudices are substituted for the consensus within the scientific community. Compare this with Casti's book[7] *Searching for certainty: what scientists know about the future*, in which he quotes Wheeler as saying "The only law is that there is no law."

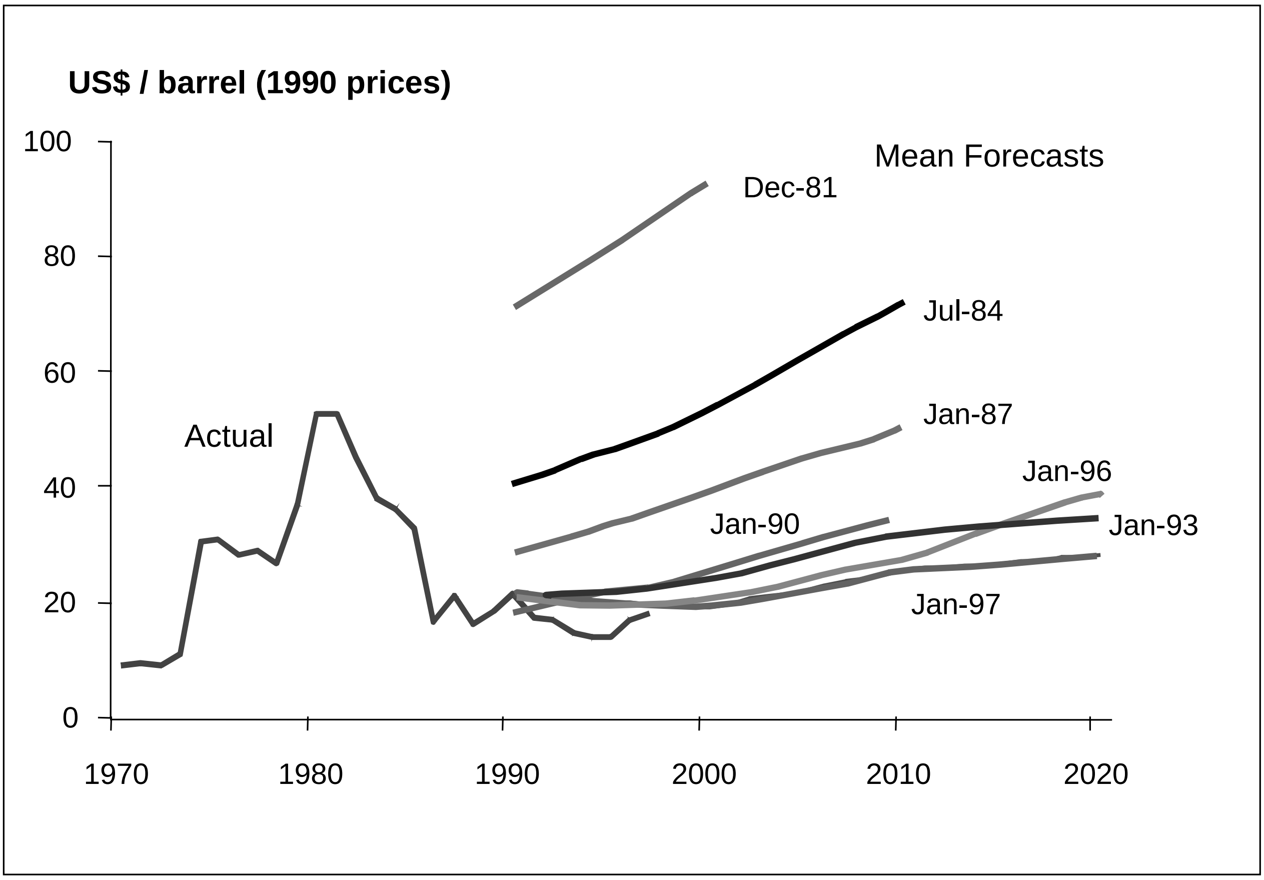
Forecasting errors, step changes and infrastructure constraints

Notwithstanding the need to make forecasts, we should not be surprised if this proves hard to do and our record of success turns out to be a poor one. One of the key challenges is to distinguish situations in which the observed patterns will continue from those in which the patterns will change. Such changes are precisely when the greatest opportunities and risks occur.

For example, consider the price of crude oil. For the last 20 years, this has been a matter of great concern within and beyond the oil industry. Judgements about future prices have a profound effect on companies' and governments' investment decisions, which in turn determine their subsequent economic performance. Furthermore, fossil fuel prices directly affect the economics of using other fuels and energy sources, so have a fundamental influence on the rate of adoption of renewable energy technologies.

As is well known, the oil price rose substantially in the 1970s as a result of action taken by OPEC members. Thereafter the price fell back steadily until it is now back at a level similar to where it began. Figure 1 compares these events with some of the forecasts of crude oil prices put together periodically by oil industry economists[8]. Throughout the 1980s and early 1990s, there was a widely held (and in the event incorrect) view that the observed fall in price would be a short-term aberration.

Figure 1. Oil prices, forecasts and reality



Source: Author.

While the oil price is influenced by many commercial, economic, political and geological factors, improved oil exploration and production techniques such as slim-hole drilling, seismic data processing methods and reservoir management and pipeline technologies have also been significant in keeping the price low.

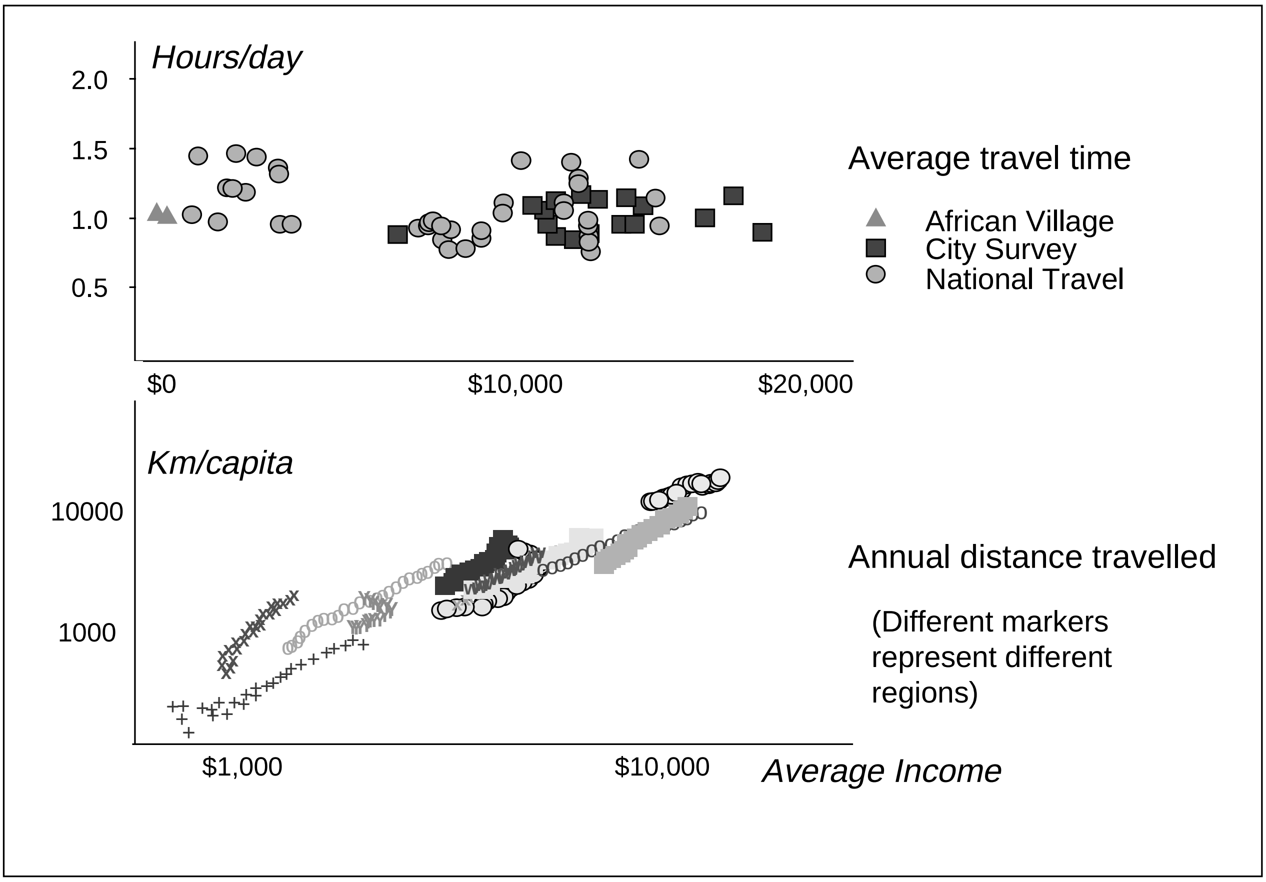
The two sharp increases in the price of oil in the 1970s gave nations and companies strong incentives to find and develop new fields that would not be subject to OPEC control. One part of their response was to invest heavily in research to develop the information processing, sensor and materials technologies necessary to reduce costs and increase exploration success rates and production efficiencies. The subsequent increase in reserves helped ensure that supply capability exceeded demand. This cycle of advancing technology, ready production and falling prices has continued to a stage where there is now large-scale consolidation of the industry.

At the commercial level, these issues link onto the handling of risk. Companies that fail by being either too conservative or too aggressive in their forecasts meet with little sympathy in the market place or on the stock market. In this example, the tendency to forecast increasing rather than decreasing oil prices had a damaging effect on the industry's economic performance. Between 1980-1993, the market value[9] of an international basket of 103 petroleum companies increased significantly more slowly than the stock market as a whole. In a sense, the companies destroyed nearly USD300 billion of shareholder value by making investments on the assumption that the oil price would stay high.

The difficulty of successful forecasting lies in the complexity of the systems of interest. The observed macroscopic trends are the result of the countless experiments carried out by people, companies and governments continually seeking solutions to the problems they face and responding to events by using and extending the tools at their disposal. These experiments succeed, or more often fail, for many reasons. Occasionally, it is because the economic limits of a particular technology have been reached and a new approach supersedes the old.

This would suggest that although our forecasts are strongly influenced by conditions today, we do not understand the reasons underlying these conditions sufficiently well to be able to predict whether they will continue or break. Figure 2 illustrates the possible consequences, using data on transport trends[10].

Figure 2. Travel times and travel distances



Source: Author.

The amount of time an average person spends travelling seems remarkably constant across a wide range of income levels, although, as expected, the overall distance travelled *per capita* increases with income. (The income/distance graph is drawn on a double logarithmic scale, and the correlation is not quite as simple as it seems.) A daily "time travel budget" of between 60-90 minutes (sometimes known as Zahavi's constant[11]) seems to apply whether one lives in an African village community or in a modern city.

Depending on your point of view, this may either represent an inherent desire to move from place to place, or a reasoned compromise between the time spent getting somewhere and then performing some activity of value. As a result, when assessing future requirements for road transportation technologies, we simply do not know which trend (if either) should be emphasised.

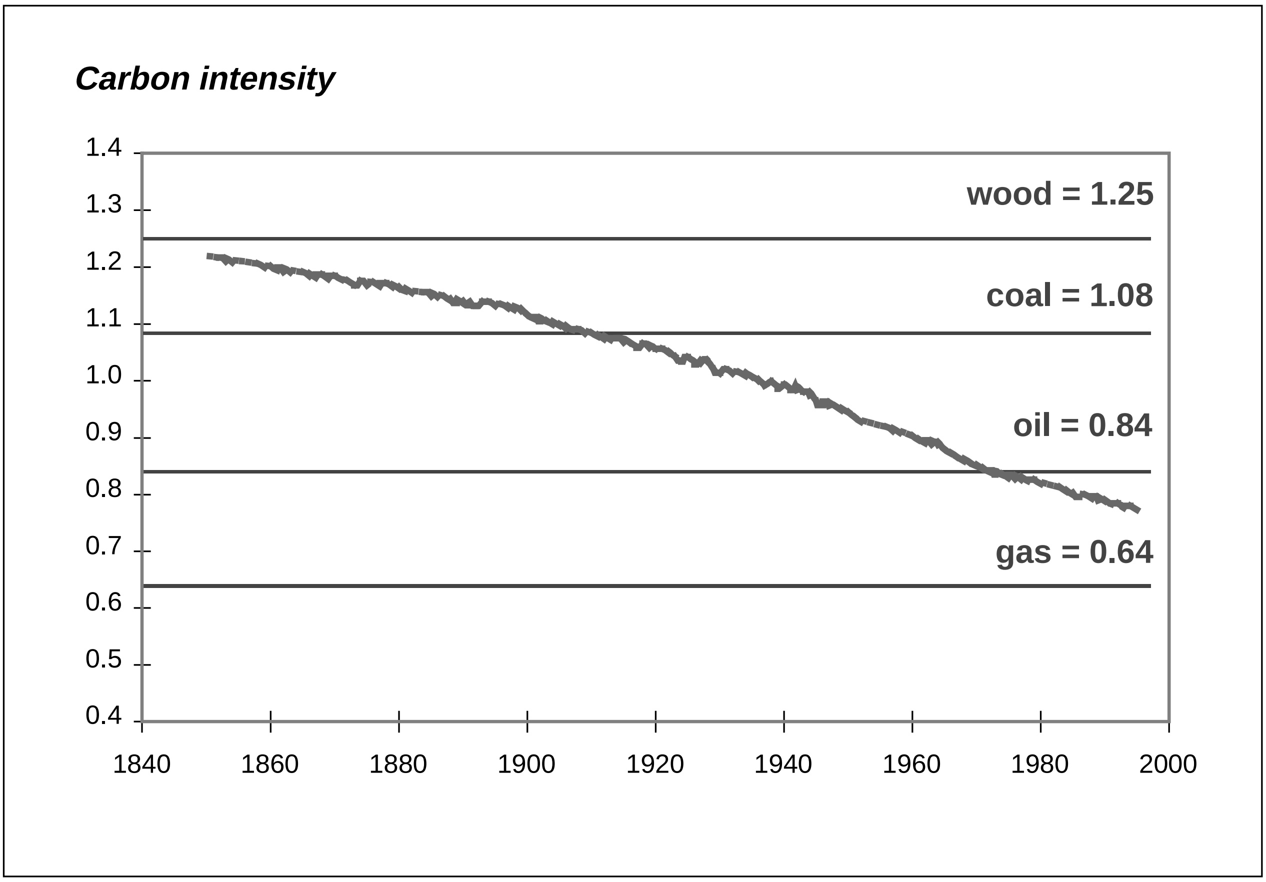
Expecting a continuing relationship between increasing income and mobility will be incorrect if people have a fixed tolerance for time spent travelling. Ultimately, the consequences of *(average road speed x daily travel time x number of people)* will impose an upper limit on this mobility[12]. Even so, this expectation would encourage legislators to mandate (and car companies to make) rapid investments in clean vehicle technologies, improved fuel efficiency, new fuels and integrated transport management systems to keep the impact of this increased mobility under control.

However, the willingness to travel may change substantially if a practical alternative becomes available. This would suggest that investment in new urban infrastructures designed for efficient 21st century living and the development of information technology based tools for routine shopping or tele-working might significantly affect travel patterns, so that mobility becomes a matter of choice rather than necessity. There is little evidence of such a trend today but then we are still at an early stage of the "information technology wave".

Whichever view proves to be true, individual players (companies, legislators, etc.) can separately only generate a certain amount of change and improvement[13]. The transport system illustrates a classic case of multi-stakeholder lock-in, placing large barriers in the way of radical development. Clean fuels are of no use without cars that run on these fuels, but these cars require that there is an adequate fuel distribution network in place. Advanced (i.e. "unusual") vehicles will not sell unless the customer trusts his local mechanic to maintain and repair them properly. And no amount of new car and fuel technology can clear congested roads. Radical change affects all the stakeholders – the public, the car manufacturers, the fuel suppliers, the legislators and the urban designers – which makes it politically and commercially very difficult to improve the situation by design.

The conclusion is that it is important to understand today's trends, but one must also consider where and how discontinuities may occur, what can prevent these happening, and what the implications might be. A second example illustrates this point.

Figure 3. Carbon intensity of global primary energy supply



Source: Author.

Figure 3 shows the secular decline in the carbon intensity of the world's primary energy supply[14]. This is the result of the long-term shift from using wood towards coal then oil, nuclear energy and gas as fuels. In principle, this trend can continue downwards towards zero, although the line will only drop below the carbon intensity of gas if we adopt carbon-free sources of energy in sufficient quantity.

Given the public distrust for nuclear power, this will almost certainly depend on the widespread deployment of renewable energy sources. Taking the arguments in this section full circle, with the prospect of continued low oil prices, it is questionable whether the costs of renewable energy can fall sufficiently quickly to counteract the effect of nations turning off existing nuclear capacities. Paradoxically, this means that a long-term decline in carbon intensity may flatten out or reverse just when society is preparing itself to deal with the issue of climate change.

Scenarios for sustainable development

Given the difficulties of making successful forecasts even without the added complexity of sustainable development, are there any tools available to help us broaden the context within which we address the task?

Scenario planning is one such tool[15]. In the first instance, this is intended to help strategic thinking by challenging participants' appreciation of the environment within which they operate and plan. The results of a scenario study include several plausible, pertinent but alternative stories of the future against which to structure this challenge. (The word "scenario" is also sometimes used to refer to the values of key parameters extrapolated from such story lines[16].)

The WBCSD has carried out a scenario study[17] to explore the dimensions of sustainable development in terms of questions such as:

- How will we recognise the resilience, the limits and the critical thresholds we face within the global ecosystem?

- What human social systems can best respond to the challenge of sustainable development?

The study generated three scenarios, each of which explores these questions in different ways. In one – *FROG!* – the response is inadequate and human social systems are unable to meet the challenge of sustainable development, a challenge made more difficult by a vulnerable natural system. In the second – *GEOpolity* – the response is to build an interlocking governance system co-ordinated at the international level. The third – *Jazz* – harnesses the markets to find solutions.

The *FROG! (First Raise Our Growth!)* scenario describes a world in which people focus on jobs, survival and short-term returns. Its mood can be characterised by a comment reportedly made by a juror at the trial following the Exxon Valdiz oil spill:

> *"You got a guy with four Ph.D.s saying no fish were hurt. You got a guy with four Ph.D.s saying, yeah, a lot of fish were hurt. They just kind of cancel each other out."*

Even though people value sustainable development, the local economic pressures mean that few steps are taken to improve welfare and raise environmental standards on the broader stage. After all, it seems obvious to (affluent) people that their neighbourhood is far cleaner and richer than it once was. As a result, the signs of global environmental problems and growing social inequity may go unnoticed, or there may be disagreement about what the signs mean. In either case, no action will be taken until matters become so serious that it is impossible to continue ignoring the problems.

In *GEOpolity*, statements such as the following capture the environmental spirit of the age and align people who have the ambition to put things right:

> *"We must make the rescue of the environment the central organising principle for civilisation" (Al Gore).*
>
> *"There is one thing stronger than all the armies in the world: and that is an idea whose time has come" (Victor Hugo).*

In a time of instantaneous communication, it is seen that new mechanisms of global governance are required to address global issues such as the health of the planet and to resolve conflicts in a peaceful manner. The palpable failure of the existing institutions, such as national governments and multinational companies, to deal with these problems means that they have little credibility. So new institutions are created to carry the mood forward.

This is likely to be a world of big, technocratic solutions to grand challenges. The institutions work with the market, but they also set the rules the market must follow.

Thirdly, there is the *Jazz* scenario. Its mood is well expressed in the following line:

> *"Integrity has no need for rules"* (*Albert Camus).*

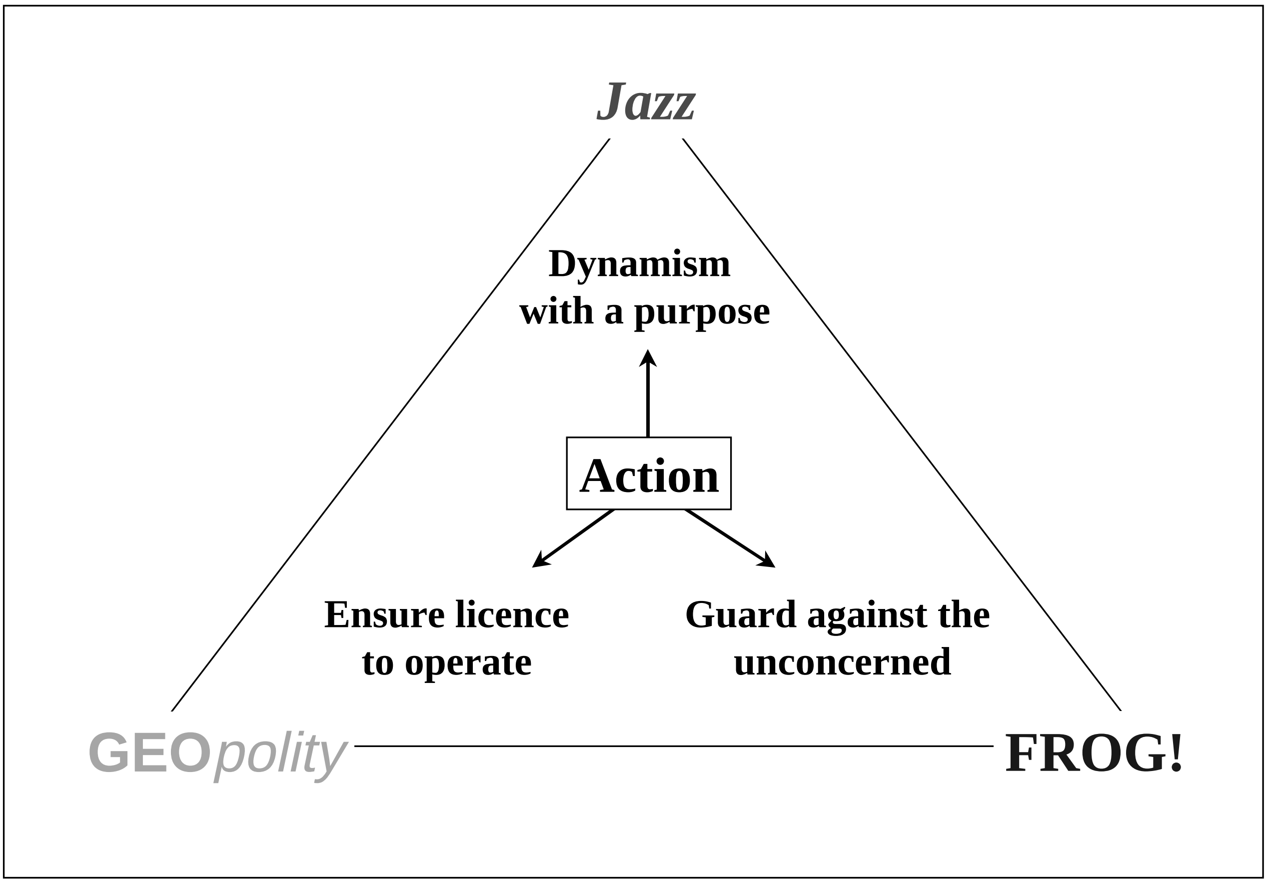
The scenario reflects a world in which people recognise that they can care about issues such as sustainable development without needing others to legislate their concerns for them. It is a complex market-led world of *ad hoc* experimentation, in which alliances form and break to meet what are primarily consumer-led demands. The high transparency that exists in an age of advanced information and communications technologies encourages quick learning, but it also allows the public to identify companies and governments that break the social norms and, as consumers and voters, to punish infractions rapidly and ruthlessly. So *Jazz* is a demanding world of dynamic partnership between consumers, businesses, governments and NGOs.

These scenarios present specific technological, social and commercial challenges. *FROG!* seems an easy if unfortunate default solution and the least likely to achieve sustainable development without a prior catastrophe. *GEOpolity* and *Jazz* are more consistent with sustainable development, although come at the problem in very different ways. These worlds share some of these characteristics respectively of a managed global economy or of a free market, but have aspirations that go well beyond these paradigms. Probably many of us would prefer to work towards *Jazz*, but recognise the day-to-day realities of *FROG!* and accept some of the political imperatives of *GEOpolity*.

Implications of the scenarios for innovation and technology

Scenarios have most value once you start to consider how to respond to them. In this process, you are not free to choose just one story line and plan your actions accordingly. All the stories have roots in the real world and any strategy will impact simultaneously upon all these roots. So it is a matter of choosing actions that can move you in the preferred direction and also safeguard against the vulnerabilities the stories demonstrate. This is illustrated schematically in Figure 4.

Figure 4. Actions and their consequences under the scenarios



Source: Author.

A key test of sustainability is "Will this action be seen to improve overall quality of life and meet the standards society is setting itself?". How this question is answered under the different scenarios will depend on the innovation, the technology and the industry sectors concerned, since no approach is likely to be inherently "sustainable" under all circumstances. The following general remarks seem relevant to the innovation process and to technology management:

- In the low-trust world of FROG!, people are primarily concerned with securing their own well-being. They will take advantage of what is offered, but will punish those who are considered to cause harm, for example as a result of the goods and services they offer. So companies will act to anticipate and limit their exposures and liabilities, and governments will ensure that exposures are discovered and dealt with promptly.

  This suggests there will be a growing, defensive emphasis on the use of measurement technologies for monitoring, quantifying and documenting environmental performance, emissions and safety.

  The low-trust mood extends to innovation in the product and service sectors. This suggests that, while there may be solid economic progress, the innovation process itself will only evolve slowly. Existing technologies will be extended before new ones are introduced, and companies will try out new ways of working and forms of partnership only when it becomes clear that this will help ensure their profitability. An economic shift from production towards services will continue as increasing numbers of products will become commodity items, but greater sustainability will not be the principal objective behind this shift.

Governments will continue to invest, set policies and support R&D to stimulate innovation, with an underlying objective of ensuring competitive national industries in the face of similar stimulation elsewhere. Some of this will reflect the ambitions of sustainable development, for example by supporting the development of renewable energy. But ambivalent consumer attitudes may make it more difficult for the products that result to penetrate the market to any great degree.

– The world of GEOpolity contains powerful new international institutions. In this world, technological prowess is a key tool by which a company can secure a social licence to operate and ensure credibility with the legislators. Since this prowess must be substantiated, once again effective measurement technology is important, seen this time as a tool for competitive advantage and potentially for shaping legislation.

  Because of the need to manage institutional credibility, companies may prefer to emphasise patentable process and product technologies (“stuff”) rather than less tangible and less easily protected knowledge-based approaches. This may slow down the trend towards a more service-oriented economy.

  To help the market move towards greater sustainability, institutions are likely to engage companies in a joint attack on big challenges. One can imagine institutionally-led research and technology-intensive initiatives (the 21st century equivalents of *Concorde*, *Apollo* and *CERN*) to attack climate change, provide equitable supplies of clean water and food, manage critical eco-systems, and ensure low-cost access to new generation technologies in order to foster greater “connectedness” and equality of opportunity.

  Considering the resources that will underpin such initiatives, technology-rich companies will see great value in encouraging and becoming contractors to these initiatives. Today’s nuclear industry developed very rapidly in a world that was rather reminiscent of *GEOpolity*.

  This world will be the most able to develop world-scale technologies such as carbon sequestration, and to achieve large-scale infrastructural changes across multiple sub-systems. It will also be an effective world for co-operative international R&D. Whether the solutions that result will be considered optimal is another matter. There are three main technological risks within *GEOpolity*: undue up-front selection of “winners”, too little customer engagement, and the unintended consequences and side-effects of technology.

– *Jazz* is a world in which technology is a cross-fertiliser that enables the diverse partnerships between different players working together to mutual benefit. One of the challenges this will place on innovative companies is to avoid any unwanted asymmetry of information with their partners while also safeguarding their own intellectual assets. This may encourage them to concentrate on making rapid use of their own (and other people’s) developments and then move on to something else. The consequence may be to place greater emphasis on the less-tangible, knowledge-rich technologies suitable within a service economy, potentially also encouraging a process of dematerialisation.

  The *Jazz* world also depends upon an unorchestrated synchronicity of attitude, which cannot happen without shared standards and information. So again, measurement technologies are required. Possibly these will be used by an emerging service industry that provides the public with environmental information and the means to monitor corporate behaviour. A trend towards dynamic networks of small, science-led companies forming around larger, more marketing-oriented multinationals, is also entirely consistent with *Jazz*. (This trend is seen today in the pharmaceutical and biotechnology sectors.)

On the other hand, overcoming some of the multi-stakeholder problems mentioned earlier might present a greater challenge within *Jazz*, especially if these require large-scale systems redesign. This world will also severely circumscribe the use of some new-wave technologies such as biotechnology (and possibly also aspects of information technology that seem socially divisive) unless the companies concerned first manage to secure a consensual basis and public ground swell for their use. The *Jazz* world will not applaud expert opinion for its own sake.

Business responses and public policy frameworks

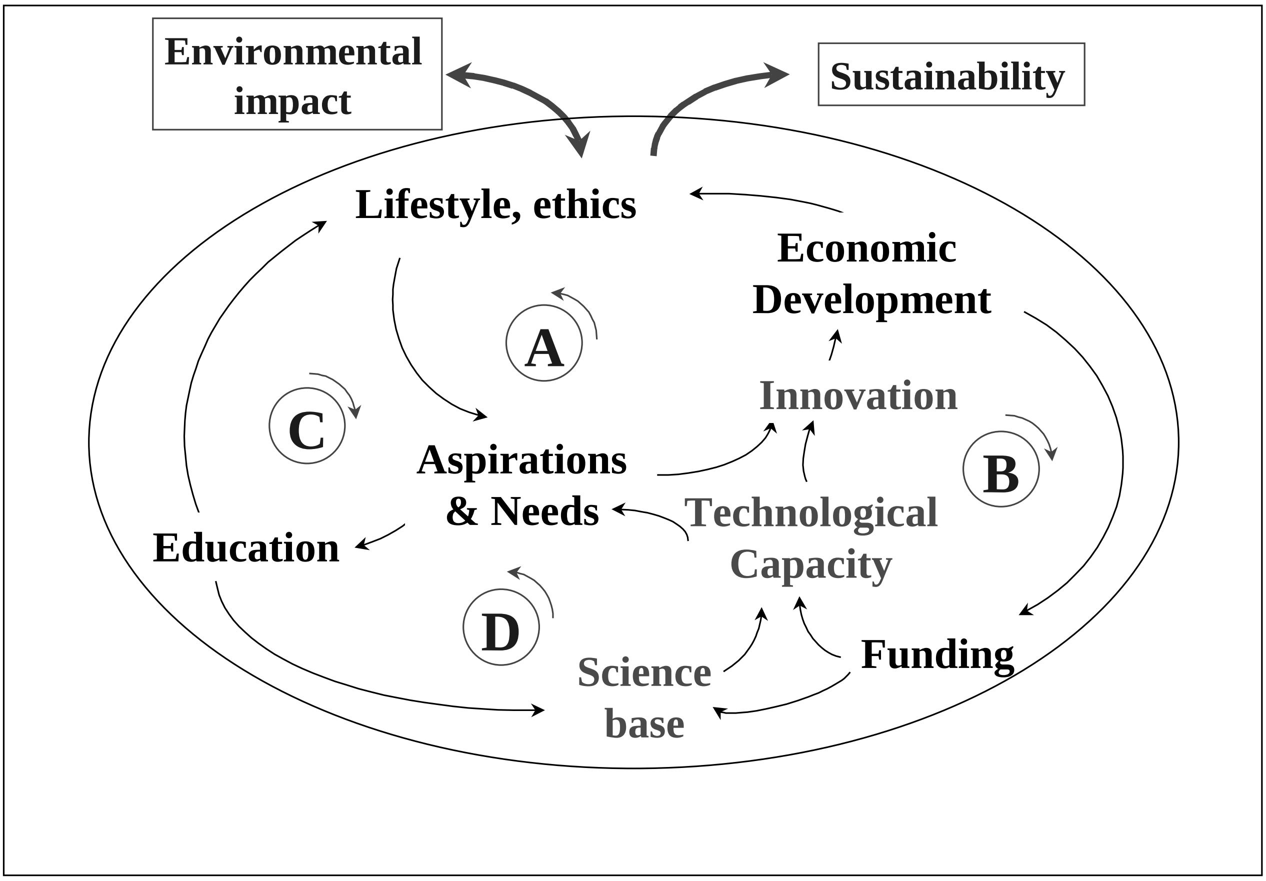
When we look around, we see companies using technology in a number of ways to support sustainable development. Some are implementing measurement technologies to quantify the tasks they have to address and provide the means to audit and report progress, and adopting more eco-efficient[18] manufacturing technologies. Approaches such as life-cycle analysis[19] and industrial ecology[20] provide conceptual frameworks for understanding technical impact at a systems level.

Some companies are changing their business model, shifting away from selling products to renting the use of these products, and introducing new manufacturing technologies to support this policy of recycle and re-use[21]. Some are setting up innovative partnerships with small, technology-led start-up companies to foster new approaches22. And some, recognising the substantial investments involved in introducing innovative new technologies, are working in partnerships with the public sector to ensure the acceptability of what they are doing.

These actions are clearly consistent with aspects of the scenarios described above. How else might companies and governments foster innovation and use technology to help secure sustainable development? Ideally, we would like to have a way to address such questions that combines scenario thinking and technology foresight within a single framework.

One approach is to use a simple systems diagram to link innovation and technology with factors such as economic development, attitudes and social aspirations. Figure 5 makes explicit some of the interdependencies discussed earlier, and shows environmental impact and sustainability as consequences of the overall systems behaviour.

Figure 5. Innovation and technology within a social framework



Source: Author.

We can then examine particular technology choices, such as those identified by foresight, and the accompanying policy mechanisms by considering their effects within the indicated feedback loops:

1. The interplay between innovation, economic development and lifestyle.

2. Between innovation, economic development and technology.

3. Between education, lifestyle and aspirations.

4. Between aspirations, education and the knowledge base.

For convenience, we can refer to these loops (A-D) as *Affluence and Consumption*, *Technical Capacity, Public Attitude*, and *Belief in Science*. Policy frameworks and technology choices that best support sustainable development will be seen to reinforce this aim within each of the feedback loops. Those less likely to support this outcome will seem discordant.

For example, within the *FROG!* scenario, the main emphasis on sustainable development is found in the affluence and consumption loop. Little is being done to enhance technical capacity, public attitude, and belief in science. This suggests that it may be possible to push this scenario world towards greater sustainability by concentrating more attention and effort within these loops. We have also commented on the risk that *GEOPolity* introduces large-scale technical capacity before the implications are understood and the public is ready to accept these.

In general, business favours approaches that focus on the desired end result rather than on the means of achieving the result, and offer stable and supportive accompanying public policy frameworks including appropriate levels of market regulation. These have been shown to be an effective way of encouraging diverse, business-led experimentation and innovation. In terms of the systems diagram, such approaches can be used to reinforce an ambition for sustainable development within the affluence and consumption, technical capacity, and public attitude loops.

Under all three scenarios, there will be continued mistrust, even fundamental disagreement, about some uses of technology, because the capacity of new technology to change our environment is increasing all the time. Honesty and openness about the risks and proposed solutions seems the most successful approach in such situations. This depends on expressing and discussing what is often complex information in ways that we can all trust and understand (and of course also being prepared to listen to each other's reactions and concerns). So we must shift these discussions away from engineering-oriented dimensions such as "will it/won't it work?" and "is it/isn't it acceptable/safe" (which *GEOPolity* is likely to encourage). The concerns show up in the public attitude and belief in science loops. They are not about technical capacity.

Other principles needed to achieve stable and supportive (and non-bureaucratic) public policy frameworks are well established. Again they depend primarily upon transparency of purpose and transparency of action, and include elements such as the following:

- Policies of freedom of consumer choice, but sufficient information and price signals to exercise informed choice. (Reinforce the ambition within the affluence and consumption loop).

- Education systems that prepare the public to discuss risks and rewards in an open fashion. (Foster public attitude and belief in science).

- A climate that fosters excellence and technological and social innovation. (Reinforce public attitude, belief in science and technical capacity).

- A climate that supports decisions based on sound data and sound science where this is possible (reinforce technical capacity), but also accepts the use of precautionary approaches where necessary. (Address public attitude as well).

- A global free market in goods and services and a sound legal framework in which the market is governed by the rule of law and sound property rights. (Ensure that the affluence and consumption loop works effectively).

- Clear constraints (along the lines of the Montreal Protocol for chlorofluorocarbons) imposed on the market after thorough public debate. (Reinforce a belief in science).

- Consistent words and actions by governments and companies, for example in their behaviour as legislators and as developers and customers of products and services. (Reinforce all the loops).

Conclusion

This paper has looked at some of the issues involved in using technology foresight in the context of sustainable development. Realising the ambition of sustainability will depend upon continued innovation, creative use of new and existing technologies, but also on far broader issues of public attitude and behaviour. Consequently, it is important to link the foresight process with matters that sit beyond the technology envelope:

- The process must consider the effect that social issues and existing infrastructures have on innovation and technological change, including how such innovation will permeate society via the market.

- It must accommodate the possibility of changes in long-established trends, without presupposing that such changes will happen or can be stage-managed.

The paper has illustrated how a scenario planning method can be used to challenge the assumptions inherent in any planning exercise, and suggested using a simple systems diagram approach to examine the consequences of particular policies and technology choices under different scenarios.

Since the intention has been to provide a firmer foundation for linking technology foresight with sustainable development, we have only referred to some of the capacities that such technologies should possess. These include permitting better measurement capabilities, lower carbon intensity energy, greater eco-efficiency, recyclability and reuse, and supporting greater social cohesion.

This last point of social cohesion is particularly pertinent. We have already noted that technology is in effect a creator of new resources. It is simply not possible to fully anticipate the response to such resource creation and the linkages and ripple effect that may occur. Each new resource enriches the options at our disposal, but will also increase the diversity of interests among stakeholders within society, and almost certainly change attitudes to what is achievable. Without a consensus about the contributions that technology is making, and should be making to sustainable development, it seems very unlikely that we will be in a position to realise these contributions effectively.

For a closing remark on foresight, it may be of interest to look back some 1350 years[23]. *Artem geometriae discere atque exercersi publice intersit, ars autem mathematica damnabilis interdicta est. Haruspex qui huic ritui adsolent ministrare concremendo illo haruspice*. Loosely translated, it seems that the study and teaching of the science of geometry are in the public interest, but whosoever practices the damnable art of mathematical divination shall be put to the stake.

Beware all ye who enter: Here be devils!

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NOTES

1. Referring in particular to the notion of the Kondratiev long wave. See *Business Cycles*, J. Schumpeter (1964), McGraw and Hill.

2. *The Paradox of Technological Development*, P.E. Gray, pp 192-204 in "Technology and Environment" (1989), National Academy Press, Washington.

3. *Technology and Global Change*, Arnulf Grübler (1998), Cambridge University Press.

4. *Risk*, John Adams (1995), UCL Press.

5. For example, action is only justified if the negative side effects can be brought to a minimum and the evils produced by these side effects are less than those produced by doing nothing.

6. *Visions: How Science will Revolutionise the 21st Century*, Michio Kaku (1998), Bantam Books.

7. *Searching for certainty: what scientists know about the future*, John L. Casti (1991), Abacus.

8. Private communication, drawn from *International Energy Workshop; Part 1: Overview of Poll Responses*, Alan Maine (Stanford University) and Leo Schrattenholzer (IIASA).

9. Study by McKinsey and Company using data from Compustat and Datastream.

10. "The Past and Future of Global Mobility", Andreas Schafer and David Victor, pp 36-39, *Scientific American* (Special Issue on the Future of Transportation, October 1997).

11. *Personal Travel Budgets*, edited by H.R. Kirby (1981) Pergamon Press. (Special issue of Transportation Research, part A, volume 15 number 1).

12. Probably at a level of mobility not too much greater than the United States has reached.

13. See *Transport, Energy and Climate Change*, International Energy Agency (1997).

14. a) Analysis carried out within Shell using historic data on primary energy consumption consolidated by IIASA and WEC (1995).

    b) A similar analysis has been given in "Nuclear Plants and Nuclear Niches", C. Marchettti (1985) *Nuclear Science and Engineering*, volume 90, pp 520-526.

15. Several books have described the scenario technique in detail, including:

    a) *The Art of the Long View*, Peter Schwartz (1991), Doubleday Currency.

    b) *Scenarios: The Art of Strategic Conversation*, Kees van der Heijden (1996), Wiley.

16. For example in *Global Energy Perspectives*, Nebojša Nakicenovic *et al* (1998) Cambridge University Press.

17. *Exploring Sustainable Development: WBCSD Global Scenarios 2000-2050*, World Business Council for Sustainable Development (1997).

18. *The 1998 Eco-Efficiency Case Study Collection*, WBCSD, developed as part of the European Eco-Efficiency Initiative in co-operation with European Partners for the Environment and supported by DGIII of the European Commission.

19. *Life Cycle Assessment: What it is and How to do it.* UNEP (1996) United Nations Publications.

20. *Industrial Ecology: Policy Framework and Implementation*, Braden R. Allenby (1998) Prentice Hall.

21. For example, by renting the use of its photocopiers, Xerox can take greater responsibility for product recycle and reuse, so is more easily able to design products with this in mind.

22. The partnership between DaimlerChrysler, Ballard and others to develop practical fuel cell powered vehicles is a good example.

23. *Corpus Iuris Civilis, Codex Justinianus*, Book IX, XVIII, 2, 3 (circa 650AD).