IPTS–ESTO
Techno-Economic
Analysis Report
1999–2000

About the IPTS

The Institute for Prospective Technological Studies (IPTS) is one of the eight institutes of the Joint Research Centre (JRC) of the European Commission. It was established in Seville, Spain, in September 1994.

The mission of the Institute is to provide techno-economic analysis support to the European decision-makers, by monitoring and analysing science and technology related developments, their cross-sectoral impact, their interrelationship in the socio-economic context and future policy implications, and to present this information in a timely and logical fashion.

Although particular emphasis is placed on key science and technology (S & T) fields, especially those that have a driving role and even the potential to reshape our society, important efforts are devoted to improving the understanding of the complex interactions between technology, economy and society. Indeed, the impact of technology on society and, conversely, the way technological development is driven by societal changes are highly relevant themes within the European decision-making context.

In order to implement this mission, the Institute develops appropriate contacts, awareness and skills for anticipating and following the agenda of the policy decision-makers. In addition to its own resources, the IPTS makes use of external advisory groups and operates a network of European institutes (ESTO) working in similar areas. These networking activities enable the IPTS to draw on a large pool of available expertise, while allowing a continuous process of external peer review of the in-house activities.

The interdisciplinary prospective approach developed by the Institute is intended to provide European decision-makers with a deeper understanding of the emerging S & T issues, and is fully complementary to the activities undertaken by other JRC institutes.

About the ESTO network

The European Science and Technology Observatory (ESTO) was formally constituted by the Institute for Prospective Technological Studies in February 1997 as a 'technology watch' network. The ESTO network comprises 34 institutions with experience in the field of scientific and technological assessment at national level, representing the vast majority of European think-tanks.

ESTO members share responsibility for supplying the IPTS with high-quality, up-to-date scientific and technological information drawn from all over the world, facilitated by the network's broad presence and wide range of contacts. Developments are examined from a socio-economic perspective, identifying breakthroughs and trends which may require action at a European level. Activities are targeted at policy-makers and decision-makers within the European S & T sector, in particular the Commission, but information is also available to a wider audience, such as the Member States, non-governmental organisations (NGOs) and industry.

Currently, ESTO is engaged in the following activities:

- contributing to the monthly *IPTS Report;*
- producing an annual techno-economic analysis report;
- developing specific prospective projects intended to act as a trigger for in-depth studies;
- building thematical networks allowing ESTO and the IPTS to provide rapid responses to specific requests from European decision-makers;
- fostering the continuous expansion of the ESTO network and the involvement of new members in activities.

IPTS–ESTO

Techno-Economic Analysis Report 1999–2000

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About the IPTS-ESTO Techno-Economic Analysis Report

Drawing on its close contacts with the international R&D community, in particular through its ESTO network, and with European Union policymakers, the Institute for prospective Technological Studies (IPTS) carries out prospective techno-economic research with the specific aim of analyzing developments in Science and Technology which are of importance for EU policies. The emphasis on the links in both directions between technology and the economic environment, and the insight of the policymaker's perspective are characteristic of IPTS' approach.

The annual Techno-economic Analysis Report is one of the ways in which IPTS communicates the result of its work, and complements the "IPTS Report" journal, studies and project reports, such as the "Futures" Report Series. This annual Techno-economic Analysis Report is a selective presentation of recent data and events, attempting to answer the question: "What are the most significant projected impacts for EU policy-making one can identify when taking stock of the scientific and technological developments the year has brought?" The emphasis is therefore not descriptive but analytical. The report tries to take a step back, on a yearly basis, to see the bigger picture over the period that has elapsed, to take stock of what is at stake and of the implications that can be drawn. It is for the reader to judge to what extent this rather ambitious objective will have been met.

This edition of the Techno-economic Analysis Report, titled 1999-2000, covers up to and including the early part of the year 2000. This period saw the start of a renewed effort by the European Union to bring to the forefront of the political agenda the crucial importance of an EU-wide, co-ordinated approach to investment in R&D. The European Research Area initiative, launched in January 2000 by Commissioner Philippe Busquin, has quickly focused the debate and is expected to lead to a general overhaul of the EU's RTD policy approach. It is our hope that this document, together with the other IPTS studies, may usefully contribute to sketching the background against which the decisions on RTD priorities and instruments will have to be made by EU political institutions.

Part I: Executive summary

Jorma Lievonen, Editor
In association with the VTT Group for Technology Studies

1.1. Introduction

This is the third annual techno-economic analysis (TECA) report prepared jointly by the IPTS and ESTO. As in previous reports, our aim is to analyse techno-economic developments during the target period — in this edition the year 1999 and early 2000 — from a European perspective.

The main goal of the report is to identify and analyse prospective techno-economic information that can be relevant and useful for European decision-makers. This report has a tighter focus than the two previous ones: for instance, instead of having a chapter on biotechnology in general, the report has a chapter on DNA diagnostics. The themes of the chapters have been chosen so that they reflect both topical concerns of policy-makers and current interests of technology developers. Table 1 puts the contents of our report into the context of the EU's fifth framework programme (FP5).

Table 1: The contents of the TECA report in the context of the fifth framework programme

Chapters of the TECA report (Part II)	Related thematic programmes of the fifth framework programme
1. Electronic commerce	Theme 2: User-friendly information society
2. DNA diagnostics	Theme 1: Quality of life and management of living resources
3. Electricity markets	Theme 4: Energy, environment and sustainable development
4. Fuel cells	Theme 4: Energy, environment and sustainable development
5. Nanotechnology	Theme 3: Competitive and sustainable growth
6. Environmental indicators	Theme 4: Energy, environment and sustainable development

The five-year framework programme was launched in early 1999. Reflecting aims expressed in the Treaty of Amsterdam, environmental sustainability is a pervasive issue in FP5, and that is the case in our report as well. Sustainability concerns are directly related to our chapters on electricity markets, fuel cells, and environmental indicators.

This executive summary forms the first part of the report and not only summarises the main messages of Parts II and III, but also presents some techno-economic developments that are not studied in more detail later in the report. Part II consists of six chapters; each of them reviews events of 1999 and early 2000 in a particular field

and analyses them in a wider context. Part III takes a look at research and technological development (RTD) policies in four non-EU countries: the United States, Japan, Russia and China.

These analyses may provide a useful contribution to the debate launched by European Commissioner Philippe Busquin's initiative "Towards a European Research Area" (European Commission 2000). It consists of an attempt to rethink and redefine the very foundations of European co-operation in RTD and its present structures. The aim is to focus concerted action by the EU on agreed high-priority areas, and to draw the attention of policy makers to the risk of reduced growth and competitiveness that could result from insufficient or fragmented research investments.

The chapters of Part II and the RTD developments in selected third countries presented in Part III of this report highlight issues that are likely to be at the core of the political discussion on the future of European RTD policy.

1.2. A year of excitement and embarrassments

One of the major international economic developments of the year 1999 was the launch of the euro. The new currency was initially well received by financial markets, but it declined during 1999 and early 2000. It was one of the reasons that prompted the European Central Bank to raise interest rates. In addition the price of crude oil was increasing and reached USD 30 per barrel by March 2000.

During the last few months of 1999, economic growth gradually gained pace in Germany and some other European countries. In Russia, the economy stabilised during the year and started to show signs of growth as the country’s trade performance improved. In contrast, the recovery of the Japanese economy ground to a halt during the second half of 1999. In the United States, the longest period of expansion in the country’s economic history was sustained throughout the year and even accelerated during the last quarter of 1999. Persistent US trade deficits, reflecting high consumer spending, added to the mounting international debt burden of the country. Overvalued prices in the US stock markets and labour shortages were, at the end of 1999, the strongest signs of overheating in the economy. At the same time concern over the plight of the lowest-paid workers persisted.

1.2.1. Information and communication technologies and the economy

Evidence from the United States supports the view that applications of information technology enhance economic growth and help to keep inflation in check by improving productivity, the ultimate source of welfare (Greenspan 1999). That information technology improves productivity is a sign that technologically advanced nations are moving gradually towards a knowledge economy and an information society. However, there is not much evidence for the ‘new economy’ in which traditional laws of economics would not apply.

In many respects, the year 1999 was a year of software. Tasks related to the Y2K (year 2000) problem occupied many corporations and public sector organisations. In

the United States, Microsoft was declared a monopoly in a finding issued by a federal judge. At the end of April 2000, the Department of Justice prosecutors asked the judge to punish the culprit by dividing the companies into separate parts. Another problem faced by the company was the vulnerability of its products to computer viruses, such as Melissa. The creator of that virus was traced and arrested; he was charged for causing damage worth USD 80 million. The rising cost of disruption caused by computer viruses was revealed when Dell, the computer manufacturer, announced that a virus had forced the company to stop production for five days at its plant in Ireland. Early in 2000, hackers embarrassed leading e-commerce sites by shutting them for hours by denial-of-service attacks.

In 1999, the Internet reached the age of 30. In October 1969, three months after *Apollo 11* landed on the moon, the first Internet host-to-host transmission took place in California (Leiner et al. 1998). In 1999, some companies that had been forerunners in exploiting commercial opportunities created by the network reported satisfactory sales from their Internet sites and forced competitors to set up rival sales and marketing efforts. Consequently, 1999 also became the year when electronic commerce made its international breakthrough. As explained in more detail in the chapter on e-commerce of this report, future wireless and broadband technologies will provide added reasons for believing that some companies will be able to attract new customers by offering advanced e-commerce services. There is even the chance that a few winner websites, initially distinguished by excellence in brand building, trustworthiness, and service, will be able to attract a high proportion of the global Internet audience and e-commerce customers (Maurer and Huberman 2000). At present, competition in e-commerce is encouraged by the relatively low cost of setting up services that can attract an international clientele. Of immediate concern, however, is that information on individual website visitors is being collected for commercial and sometimes even criminal purposes.

1.2.2. Breakthroughs in biotechnology

The basis for future technological upheavals and eventual business opportunities is now being created in many fields of biotechnology and life sciences. In April 2000, the US company Celera Genomics announced that it had completed the gene sequence of one human being. The first representatives of new antibiotics (streptogramins and oxazolidinones) have gained regulatory approval. It is expected that these medicines will give a respite of a few years in the fight against pathogens that have become resistant to other antibiotics.

Surprising results of research on adult stem cells were published by a joint Italian and Canadian research team in early 1999. Nerve stem cells started to produce blood cells after being injected into mice from which blood stem cells had first been eliminated. (Bjornson et al. 1999.) Further evidence of the flexibility of stem cells was discovered at the end of the year when it was shown that mature liver cells can be generated from bone marrow cells. It will take time before the mechanisms involved in such transformations of identity will be fully understood. These discoveries encourage hopes that in the future tissues can be produced from stem cells and used as transplant organs.

In an animal trial in Boston, bladders grown in a laboratory were successfully used as implants. The bladders were grown from bladder tissues and when implanted they developed vascular and nerve connections and the animals gained normal control functions. It was the first demonstration that it is possible to engineer a complete organ *in vitro* and use it successfully as a transplant. (Oberpenning et al. 1999.)

Another exciting field of medical biotechnology is DNA diagnostics, on which there is a chapter in this report. The promise of DNA chips is that in the future they will enable doctors to tailor medical treatments according to genetic and metabolic features of individual patients, strains of pathogens and subtypes of cancer cells. Even before practical clinical applications become available, DNA chips will be applied in medical research to elucidate the true underlying molecular mechanisms of many diseases that are still not understood. DNA chips are already used by pharmaceutical companies in the development of new drugs. Europe clearly needs to enhance its RTD efforts in DNA diagnostics.

While the general public seems to be eager to accept new medicines, medical procedures and industrial production methods arising from biotechnology, attitudes against food containing ingredients from genetically modified organisms (GMOs) hardened in 1999. In the United Kingdom, a consensus was reached on removing GMO foods from supermarket shelves. In the wake of the BSE epidemic and revelations about the use of waste in animal feed, the European public has grown suspicious of non-traditional food production technologies. In the United States, the debate on genetically engineered crops intensified during 1999, as possible side-effects of the technology were discussed in the press.

1.2.3. Sustainability and competitiveness in energy technology

Competition is a major force in motivating innovation. In 1999, Europe took the international lead in freeing competition in the supply of electricity. The first phase concerned mainly large industrial customers, but eventually small-scale power plants will have to respond to the challenge of increasing competition and lower prices. Time will tell whether increasingly international large-scale electricity producers and local producers can coexist in the electricity markets. Small local plants could have several advantages. Their distribution costs are low and their energy efficiency can be high, if they cogenerate power and heat, which also reduces their environmental impacts. The key to success may well be in technology development. In the chapter on electricity markets, the focus is on environmental sustainability. Can lower electricity prices be reconciled with environmental goals?

Except for cost, fuel cells would be an ideal solution for combined heat and power production. Hydrogen-powered fuel cells are silent and do not release any environmental emissions directly. In the future, small fuel-cell plants using other fuels can be expected to produce power and heat for residential districts or individual buildings. As detailed in the chapter on fuel cells, it seems that commercial fuel-cell devices will be available for residential use within a couple of years.

While large electricity producers have specialised in economies of scale, they face the challenge of keeping in touch with the changing values of society at large. In a demonstration of distrust of nuclear power, Sweden closed one of the country's 12 nuclear reactors at the end of November 1999. The worst nuclear accident of the year took place at the end of September in Tokaimura in Japan when a nuclear chain reaction was started by workers who added too much enriched uranium to a tank. The plant had been plagued by incidents seemingly related to problems in safety culture. Three workers sustained serious injuries immediately and at least 80 people were exposed to radiation (Nuclear Safety Commission of Japan 1999).

As environmental issues are receiving a great deal of attention, there is an expectation that progress is being made. But who can tell? While most people agree that indicators such as gross domestic product (GDP) or rate of inflation are relatively accurate and valid measures of comprehensive economic trends, widely accepted indicators do not yet exist for changes in the state of the environment. The chapter on environmental indicators reviews the long-standing efforts on which definitions and published figures are based. It is possible that in the future we can compare economic indicators such as GDP growth with changes in environmental indicators in order to determine whether or not our economy is moving towards sustainability.

The expectations on nanotechnology have been raised by a few advocates of the field. The chapter on nanotechnology shows that steps are indeed being taken to develop and apply the methods of this branch of technology. Eventually, existing electronic components are going to be replaced with much smaller, faster and cooler devices. Photonic systems of the future are going to reduce the energy consumption of our computer and communication systems, while increasing their performance.

The reason why progress is still slow in many areas of molecular research is that we do not yet fully understand the complex molecular interactions between materials. Some progress in explaining what goes on between water molecules was reported in January 1999 as researchers working at the European Synchrotron Radiation Facility (ESRF) in Grenoble announced that they had confirmed for the first time unambiguously that electrons in the hydrogen bond are covalent in water, as had been predicted by Linus Pauling in the 1930s (Isaacs et al. 1999). The finding paves the way for progress in explaining in detail the reactions that take place in water solutions in living cells. It also signifies that much painstaking work is still needed before complex chemical interactions can be controlled perfectly at the molecular level.

1.2.4. Excitement in space and suspense in satellite phones

In aerospace, the competitive position of Europe was strengthened in 1999. In October, the DASA wing of German DaimlerChrysler AG and French Aérospatiale Matra SA agreed to join forces to create the world's third-largest aircraft and defence company with almost 90 000 employees. The new venture, European Aeronautical, Defence & Space Co. (EADS), has an 80 % stake in the Airbus Industrie passenger-jet consortium, while the remainder belongs to British Aerospace. The new venture

has to prove that its dual management structure will work and that it can overcome problems that are often associated with mergers: disappointing profitability and internal tensions. Furthermore, Arianespace carried out the first commercial mission of an Ariane 5 rocket, lifting a European X-ray astronomy satellite into orbit. In June 1999, the European Union Council of Ministers for Transport decided to start the definition phase of the Galileo global navigation satellite programme. The system is expected to be fully operational in the year 2008, when it will comprise more than 20 satellites.

Meanwhile, China took a long step towards becoming the third nation to send a man into space. The country's first experimental spacecraft completed a short mission in space and then touched down in Inner Mongolia. Japan, however, experienced problems with its H-II rocket systems.

The year 1999 was a difficult one for satellite phone companies. In August, the US company, Iridium, announced that it had defaulted on two of its loans. The USD 5 billion venture filed for protection from creditors while trying to carry out financial restructuring. Two weeks later, another satellite communications company, ICO Global Communications, originally launched by the maritime satellite specialist Inmarsat, suffered a similar fate. Its prospects were lifted by cash infusion from Teledesic, a company that hopes satellites can provide broadband Internet access for mobile users. The lesson derived by commentators on these developments was that currently the profitability of ventures based on capital-intensive infrastructure investments can easily be eroded by advances in rival technologies even while the infrastructure is being constructed. In any case, one satellite phone operator, Globalstar, managed to start its operations in September 1999.

1.2.5. International research policy developments

The four chapters in Part III discuss some of the leading RTD countries outside Europe. These chapters definitely prove that decision-makers not only in the United States and Japan, but also in Russia and China are well aware of the significance of science, knowledge, skills and technology in the modern economy. A deeper understanding is also developing of conditions in which scientific and technological progress flourishes. It seems that key national organisations are making great efforts to become more aware of the strengths and weaknesses of their respective national systems of innovation and are trying to learn from the experiences of others. The multifaceted process of learning and adjustment promises continued advances.

1.3. Conclusion

Despite all technological progress reported during 1999, our concluding note stresses caution. The loss of two American Mars probes constituted the most important scientific disappointment of the year 1999. The crash of Mars Climate Orbiter was caused by the fact that English rather than metric units were used in one part of the

computer software in the spacecraft. Mars Polar Lander was probably lost because false signals from its legs led to an automatic shutdown of the engines during the descent to Mars. The immediate causes of these failures were technical, but the real problem in both cases was inadequate testing. The strive to save costs and to keep to schedules were given too high a priority. (Mars Program Independent Assessment Team 2000.)

Every technical venture and device has its risks. The high cost of eliminating the Y2K software problem shows why simple standards should be adhered to in technology. The Tokaimura nuclear accident demonstrates what the human cost of an inadequate safety culture can be. If safety problems are perceived as intractable or too expensive to deal with, there is a danger that society as a whole will become blind to the problems. An obvious example is our inability to react to the fact that 40 000 Europeans die each year in traffic accidents. Professionals and managers involved in technology development, product design and safety management have a special responsibility to take fully into account the unforgiving nature of technology.

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Part II: Techno-economic developments

1. Electronic commerce: innovation and consolidation

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Summary

The year 1999 saw continued interest in electronic commerce from policy-makers, industry and the stock market. Major e-commerce businesses continued to make operational losses, and the problems of existing e-commerce services became apparent during peak shopping periods. The first official statistics showed that in the United States e-commerce accounted for less than 1 % of total retail sales. At present, e-commerce is mainly an alternative sales channel competing with others. Electronic commerce is likely to benefit from increasing sales of non-physical goods and services. The true potential of e-commerce will be reached if the required framework for business-to-consumer transactions can be devised. Adequate measures have to be taken to guarantee data protection, security, privacy, taxation and consumer rights. An infrastructure permitting the interoperability of small-value payment systems is also essential. Although parts of Europe might be lagging behind with respect to the uptake of e-commerce, any remaining gaps can be closed when the transition to mobile platforms and widespread use of intangible goods and services has taken place.

1.1. Introduction

Several events during 1999 signalled the growing importance of the Internet, and more specifically its economic worth as a vehicle for electronic commerce.

- In November, the Council of Telecommunications Ministers adopted the electronic signature directive. Electronic signatures are required for transactions over the Internet or other electronic networks in which there is a need to authenticate the identity of one or more participants.

- In December, an agreement was similarly reached on the e-commerce directive. Companies can use websites to sell goods throughout the EU as long as they comply with regulations in force in their home countries.

- In December, the Commission's President, Mr Romano Prodi, announced the e-Europe initiative, which aims at furthering the adoption of the Internet and e-commerce in all spheres of European society.

- In the United States, the first official estimate on the volume of e-commerce was released in March 2000. It revealed that retail sales through online systems totalled USD 5.3 billion or 0.64 % of all retail sales during the last quarter of 1999. The estimate does not include sales by travel agencies, stockbrokers or ticket sales agencies. (Department of Commerce 2000.)

- Companies and industrial organisations as well as national and international standardisation bodies adopted the Internet's new extensible mark-up language (XML). The XML increases the capabilities of web browsers to handle information formats that are useful in e-commerce and other specialised applications.

- In the future, wireless communications devices may be widely used to access Internet-based services and to perform e-commerce transactions. In 1999, the first commercial applications of the Wireless Application Protocol (WAP) were introduced, paving the way for such development. Mobile electronic commerce is predicted to be the next area for contest in the global marketplace.

- Internet and e-commerce related companies were valued at very high levels on the stock markets, and founders of many start-up companies were able to attract huge amounts of capital. In January 2000, America Online (AOL) realised its high stock value by buying Time Warner which had a much more solid basis in real assets.

- In early 2000, hackers attacked major commercial websites and brought them to a halt for several hours at a time. In January 2000, it was reported that a hacker from eastern Europe had stolen, published, and probably sold to criminal gangs credit

card information on 300 000 customers of an e-commerce CD merchant. Incidents of this kind obviously undermine consumer confidence.

Electronic commerce comprises sales of goods and services through the Internet, electronic data interchange (EDI) systems and other information networks. Payment can be made online, but frequently is not. The following discussion will concentrate almost entirely on the business-to-consumer segment, although in terms of sales it is surpassed by business-to-business e-commerce. From the political point of view, the business-to-consumer segment is more topical, since there are such issues at stake as consumer protection and privacy.

Digital products that can be distributed via information networks — text, pictures, software, and music — are particularly well-suited for e-commerce. Similarly, goods that can be easily delivered by mail — books, CDs, and videos — have attracted consumer interest. Trading in various kinds of tickets as well as in company shares is also widespread. However, even the best-known players are struggling to break even. Like the shovel manufacturers in the great Gold Rush, the first winners are likely to be companies that supply software and equipment needed in electronic business. According to a recent study, US companies spent USD 150 billion on e-business infrastructure in 1999, and spending could still double by 2003 (Taylor 2000).

1.2. Facts and figures on electronic commerce

Electronic commerce is currently regarded as one of the key growth areas of business. However, predictions for its expansion vary widely and are frequently biased by economic interests (Meijers 1999).

It is customary to make a distinction between business-to-consumer (B2C) and business-to-business (B2B) transactions. It has been estimated that B2B transactions accounted for 84 % of all Internet transactions in the United States in 1998 (Greenberg 2000). For companies, e-commerce can create savings in purchasing expenses. In 1999, car manufacturers were arranging online systems which would enable them to find more easily the least costly suppliers for each required part. Electronic-commerce makes it possible for companies to streamline their operations and organisations to take full advantage of direct contacts with suppliers and customers in an increasingly globalised marketplace.

For consumers, e-commerce seems to offer mainly an alternative channel for purchasing. According to one survey, only 6 % of online commerce constituted incremental sales that otherwise would not have taken place (Jupiter Communications 1999a). While consumers may be willing to do one or two test buys, creating genuine customer loyalty will be the acid test of e-businesses in the impersonal world of online trade. For these reasons, the early euphoria on B2C e-commerce is starting to evaporate. Observers are beginning to take stock and are likely to make their future predictions more cautious and conditional.

The fact that the volume of e-commerce in the United States during the October to December period of 1999 was only USD 5.3 billion (of total retail sales of USD 821.2 billion) will have a sobering impact on future predictions. Apart from the US figures, there are virtually no reliable statistics on the actual volume of B2C trade over the Internet, although several countries have announced their intention to set up official reporting schemes. Most figures are at best based on market surveys among a limited number of respondents.

Table 1 combines European figures from two sources. The figures for 1999 were obtained from a survey by the Bonn-based market research company, Empirica, while those for the previous year come from a recent ESTO report on electronic payment systems in Europe.

Table 1: Consumer expenditures on the Internet in selected countries, 1998 and 1999

Country	Internet trade 1998 (EUR per capita)	Spending in 1999 by persons who made purchases online (EUR)	Market volume 1999 (billion EUR)
Denmark	4.9	159	0.7
Germany	1.6–6.1	51	3.6
Spain	0.5	10	0.4
France	0.3–1.0	77	3.4
Italy	2.8	21	1.1
Finland	n.a.	200	0.8
Sweden	7.5	102	0.7
United Kingdom	0.8–10.2	n.a.	10.3
EU-15	1.0–4.1	—	—
Japan	3.5	—	—
United States	50.0	—	—

NB: Empirica figures refer to spending by those persons who actually purchased online and not to the entire population above the age of 14 in the countries concerned.
Sources: Böhle et al. (1999) for 1998 figures: 124–125; Empirica (1999a, 1999b) for 1999 figures.

A recent small-scale pilot survey by the Dutch research company, Pro Active International (1999), suggested that somewhere between one third and one half of European Internet users have already bought something online. Northern Europeans were more active e-customers than those from the south. Meanwhile, a 1999 US survey indicated that members of about one third of US households having Internet access had made online purchases (GartnerGroup 1999). The figures reveal that behaviour patterns regarding Internet access and participation in e-commerce are remarkably similar in Europe and the United States, although the European Internet population is smaller.

The types of goods and services purchased over the Internet vary from one country to the next, but overall the most frequent trade involves computer hardware, books, music (compact discs), computer software, travel and entertainment booking and

banking. One of the most publicised successes of e-commerce has been the proliferation of online auctions. The Californian e-Bay site has been a commercial success since its earliest days, and very much an exception to the usual experience with e-commerce.

1.2.1. The European lag — Is it real?

In Europe, there is concern that 'missing the boat' of electronic commerce and failing to capture a considerable share of the world market would have grave and lasting consequences. Actually, e-commerce was well-established in Europe even before the Internet was ever used for the purpose. In France, there was Minitel and in Germany Btx, and there are adequate payment systems, at least for domestic e-commerce, in almost all countries. Europe has played a leading role in such technologies as smart cards, hypertext mark-up language (HTML), and WAP. Major deficits probably exist in marketing, where US firms such as Amazon have set examples, and financing — European financial institutions would probably not tolerate financial losses of the kind Amazon and some other 'dot-coms' have been making.

Pro Active's Dutch national Internet monitor (cf. Böhle et al. 1999) says that most cross-border business-to-consumer electronic commerce goes to merchants located in the United States. What is unclear is which proportion of this flow is due to an absence from the market of domestic or European merchants, and which proportion is due to customer demand for products that are not readily available in Europe. There will obviously also be a corresponding demand for European products from the United States.

It has been argued that any existing gap is still small enough to provide later entrants, including European players, with the opportunity to learn from experience and to avoid the mistakes already made by others. Judging from the existing estimates, European consumers are rapidly discovering electronic commerce, although there are still vast differences within Europe. To give just a single example; as recently as 1997, the Finns were described in an ESTO report (Tang 1997) as being extremely hesitant with respect to e-commerce, whereas Table 1 illustrates that they are at least among the leading spenders. On the vendor side, many large companies are currently using websites as virtual shop windows, making the transition to serious e-commerce only when they perceive sufficient interest from consumers.

1.2.2. Internet access devices

According to Green (1999), there are three stages of e-commerce readiness: personal computer (PC) ownership, online connection, followed by online transactions. The *Eurobarometer* of March 1999 states that 30.8 % of all EU Member State households had a PC in late 1998. The corresponding figure for US households was 50 % (against 27 % in 1995). The US statistics show that the majority of home PCs are equipped with older, slower processors and modems. A recent US news survey shows that many home PC owners are unwilling to upgrade for fear of the new machine rapidly becoming outdated (US News Online 1999).

For September 1999, Nua Ltd estimated the total European Internet population (including the non-EU countries) at 47.2 million, while the corresponding figure for the North American continent was 112.4 million. The Asia/Pacific region had an estimated 33.6 million users, of whom roughly half (18 million, or 14.4 % of the country's population) were in Japan. In mid-1999, 9 % of all households in western Europe were estimated to have Internet access. The number of persons in Europe estimated to use the Internet was as high as one fifth of the population, ranging from just under 6 % in Portugal to 38 % in Norway.

Among the main reasons for the European lag in embracing the Internet are the high costs of local telephone calls required to dial into the web and the costs of subscriptions to access and service providers. There has been a great deal of movement in this respect, due in part to the deregulation of telecommunications and increased competition among service providers. Individual providers have been providing free Internet access, some going as far as paying telephone costs, and others offering discounted prices on dial-in and connection costs. Reluctance to adopt new technologies, a factor frequently mentioned to explain the lag, cannot be a real reason, since some European countries lead the United States in the adoption of other technology-based applications such as online banking or mobile phones. Another factor that is particularly relevant to e-commerce is lack of consumer confidence (cf. Section 1.3).

The European Commission seeks to foster competition in the provision of local telephony services and thus drive down Internet access costs. The Commission's initiatives to provide unbundled access to the local loop are of great importance not only in lowering local telephone and Internet access costs, but also facilitating the availability of greater bandwidth through digital subscriber line (xDSL) technologies. The Commission has set a target date of December 2000 for the provision of unbundled access for third parties to the local loops of incumbent service providers. (European Commission 2000.) The experience on the deregulation of long-distance telephony shows how increased competition could bring down the costs of local telephony and Internet use dramatically in Europe. Lower costs could also benefit e-commerce, and broadband transmission capacities should open the door to a wide range of intangible products, including video-on-demand and television services.

Over the years, the PC has established itself as the principal Internet access device, so much so that a 1997 ESTO report on electronic commerce examined no alternatives, arguing that PC prices would restrict electronic commerce to a fraction of the overall population (Tang 1997). Since then, it has become increasingly clear that mobile phones, television set-top boxes and even game consoles have great potential for expanding electronic commerce.

One of the features of television set-top boxes that makes them suitable for electronic commerce is the incorporation of smart-card readers, which are needed for pay-per-view functions. In the future, smart cards could be used both for payments, given the existence of an appropriate infrastructure, and to store certain products, services or tokens. The smart-card reader is included in many mobile phones, and the EMV specification developed by *E*uropay, *M*asterCard and *V*isa is versatile enough to be applied in a number of settings, such as vending machines, telephones and PCs

(EMVCo 1999). However, it has been argued that the EMV smart cards are too cumbersome, and as a result 'virtual credit cards' have been developed by Trintech and Motorola.

With the transition of e-commerce to 'm-commerce', in which the main platform will be mobile telephones, Europe's position is predicted to improve due to the greater acceptance and penetration of mobile telephony in Europe than in other regions of the world, which is due in no small amount to early agreement on the common GSM standard. An analysis by Forrester Research (1999b) argues that m-commerce will not be driven by the availability of the new technology, but by partnerships between the goods manufacturers and providers of 'compelling content'.

Several alliances between mobile phone producers and other major players, such as those between Ericsson and Visa or Nokia and BT, emerged during 1999 with the aim of promoting WAP Internet use. The synergy between the bank-issued smart payment card and the mobile handset has been described as 'very powerful' (Birch 1999: 7). There are already trials in Europe involving WAP-based services and e-purses, smart credit cards (Visa/Merita Nordbanken) or bankers cards (France Telecom/Carte Bancaire). It seems likely that multi-application smart cards and financial value added services will be central in the new phase of mobile services.

A 1999 study by IDC comes to the conclusion that WAP will not achieve a breakthrough in Europe before 2001. Forrester also predicts that it will be 2001 before there is any real action in m-commerce, and that a mass market will not emerge before 2003. The current SMS (short-message service) fulfils many of the WAP functions. There is also something of a vicious circle: since there are currently only a few Internet sites coded in the new WAP formats, consumer interest in equipment is only moderate, and since this is the case, only a few site owners are prepared to invest resources in making their sites WAP-compatible. In addition, the next generation of wireless telephony is already visible in the shape of the UMTS (universal mobile telecommunications system). UMTS licences have already been awarded in several European countries. It might be argued that there is built-in obsolescence in WAP.

1.2.3. Predictions for the coming years

Forrester Research (1999a) expects online revenue from business-to-business transactions to grow to USD 1300 billion over the next three years, with a corresponding prediction for the business-to-consumer sector at a mere USD 108 billion. According to a late 1999 survey by the Boston Consulting Group, one quarter of all US business-to-business purchasing will be done online by 2003. The sectors that stand to gain the most from this development are retail, motor vehicles, shipping, industrial equipment, high-tech, and government. Although Europe is lagging behind the United States in the business-to-business sector, it is expected that the gap will close over the next few years (Hillebrand 2000).

By 2004, over 40 % of e-commerce revenue is expected to be generated by 'intangible' consumer goods (notably online services and information), 20 % by 'business' products, followed by 'tangible' consumer products.

Intangible products and services are probably those best suited for electronic commerce and, indeed, it might be argued that this is the only true form of electronic commerce. The digital market may be divided into three segments. The first comprises digital products, such as static documents (texts, images), dynamic documents (sound, video, multimedia) and software. The second consists of digital services, such as translations, HTML checking, and diagnostics. The third segment covers digital tokens or certificates, such as tickets, travel bookings, vouchers or contracts (cf. Böhle and Riehm 1998). Since digital tokens and certificates are suitable for delivery over mobile phones, Europe has the know-how and infrastructure to capture a sizeable market share in this segment.

IDC expects European e-commerce merchants to begin an 'invasion' of the US consumer market in 2000, arguing that pan-European companies are actually better equipped than their US counterparts to deal with international commerce issues, such as those related to language, currency, regulation, logistics, and culture. This hypothesis is not necessarily supported by reality: a study on e-commerce by Stiftung Warentest shows that most European Internet sites only offer information in their own language, and usually also English, with less than 30 % providing information in languages such as French or German. Information in other languages was only available in exceptional cases. (Gerth et al. 1999.)

Although online retail sales are expected to continue growing at impressive annual rates over the next five or so years, they are also expected to level off after this growth period. This trend will be accompanied by a tendency towards increased average spending by as much as 300 % per customer. A report by the University of Pennsylvania's Wharton School of Business, based on a long-term panel survey, predicts an 'e-commerce plateau' as the novelty of this way of shopping wears off, the number of new buyers grows more slowly than in the past, and the number of repeat customers dwindles over time.

A new class of retailers of tangible goods is emerging. These 'bricks-and-clicks' companies take advantage of detailed knowledge about specific customer segments to sell products. Retailers of this kind will not be confined to a single retail channel, making use instead of multiple channels, such as stores, catalogues, call centres, websites, interactive television and mobile devices. Such businesses are likely to be well positioned to meet the challenges ahead in inventory management, shipping, returned goods, and customer service. With a few notable exceptions, such as Amazon and e-Bay, the new breed is likely to consist of familiar names from the 'bricks-and-mortar' world. IDC even foresees the disappearance of the so-called 'pure play dot-coms', meaning those merchants who use the Internet as their sole sales channel. (IDC 2000.) Even such e-commerce giants as Amazon will have to get a foothold in the real world.

1.3. Regulation, privacy and taxation

Major security, privacy and confidence concerns are largely unresolved and form the major barrier to electronic commerce. According to Jupiter Communications, 64 % of

online consumers are unlikely to trust a website, with many concerned about the security of credit card details online (Jupiter Communications 1999b).

An international survey carried out for IBM shows that 40 % of Internet-using consumers had decided not to purchase something online due to privacy concerns. Similarly, 63 % had refused to give information to websites when they perceived that their private information would be compromised or when privacy policies were unclear. Most consumers (76 % worldwide average) felt that they had already lost control over how companies use their personal information; 70 % believed that protecting consumer privacy was impossible. (IBM 1999.)

Since the European Union is committed to completing the single market, there is a unique opportunity for killing two birds with one stone. It is possible not only to solve some of the problems of ordinary cross-border trade, but also to create a favourable environment for European e-commerce in the process. For instance, one of the factors that deter many consumers from purchasing across borders is uncertainty as to their legal rights when exchanging or returning articles or making claims for non-delivery. A major problem in this respect is that many websites do not present adequate information on these issues. The directive on distance selling (Directive 97/7/EC of 17 February 1997) is relevant not only for the established mail-order business, but also for electronic commerce.

To what extent should these issues be left to self-regulation? Or is there a need for intervention by authorities at the European or Member State level?

1.3.1. Self-regulation or intervention by authorities?

The Internet has a tradition of self-regulation. Until now, the United States has largely dominated the development of the Internet and e-commerce with its hands-off approach. However, international attitudes on privacy and data protection vary a great deal. ‘On many issues including awareness and concern about data privacy it is the ‘‘US against the rest’’. Even our Canadian respondents look more like Europeans than their neighbours to the south’ (Kobrin and Johnson 1999: 11). The differences are partly due to fundamental differences regarding the value of privacy and the role of the State. One extreme, which most likely reflects US majority attitudes and thus characterises web traditions, is that privacy is a negotiable good, a commodity which can be traded for advantages on the market. The other extreme is that privacy is seen as an inalienable human right.

In December 1999, OECD governments arrived at a non-binding agreement on consumer-protection guidelines for e-commerce. The guidelines:

- reflect ‘existing legal protection available to consumers in more traditional forms of commerce;
- are intended to encourage private sector initiatives that include the participation of consumer representatives;
- emphasise the need for cooperation among governments, businesses and consumers at both the national and international level’. (OECD 1999.)

One argument put forward in favour of self-regulation is that time is needed to negotiate international agreements on official regulations. The following box outlines two ongoing initiatives for self-regulation.

Two voluntary frameworks for electronic commerce

There are at least two ongoing initiatives aiming to create some kind of voluntary framework for electronic commerce. The 200 members of the 'Global Business Dialogue on Electronic Commerce' (GBDe) include AOL, Time Warner, IBM, DaimlerChrysler, Bertelsmann and Fujitsu. The GBDe has published a series of policy papers on such issues as liability, consumer confidence, taxation and tariffs, and market access. In September 1999, the GBDe published its guidelines, which include suggestions for dealing with harmful or illegal content, protecting personal information, enforcing copyrights, and handling disputes between consumers and online retailers located in different countries. Among the GBDe's suggestions is a voluntary system of 'trust marks', seals of approval awarded by consumer groups or independent organisations to websites that have agreed to handle consumer addresses and credit card information responsibly.

The other major initiative, 'The Standard for Internet Commerce', was initiated by the publishing company Ziff-Davis and has attracted many major actors in Internet commerce. It has published a draft standard and launched a widespread vote on its acceptance by Internet users. The final content of the draft was determined by a vote of the initiative's founder members, i.e. the major businesses involved, and was announced to the public in December 1999. Among the aspects of electronic commerce covered in the standard are information on the merchant, information integrity and warranty policies, product and service support information, applicable law and jurisdiction, payment options, and cancellation, return and refund policies, as well as credit charging policies.

The system of trust marks, which is frequently recommended as a measure to ensure confidence in e-commerce, has come under criticism recently due to the refusal of one of the leading trust mark organisations to investigate violations of data privacy by two of its major sponsors. Although the organisation has investigated complaints by customers, it has never actually revoked the right to display the trust mark, despite 'coming close'. Thus it can be argued that a seal does not necessarily indicate that the site adheres to the principles in the contract for the seal. For consumers, privacy seals are among the least important criteria in deciding whether or not to provide information to websites (Cranor et al. 1999).

The EU directive on data protection prohibits transfer of personal data to countries that do not ensure an adequate level of protection, including the United States. Implementation of the directive has been delayed, but it is possible that transfers of any and all name-linked data from the EU to the United States could be prohibited. Many US companies are voluntarily complying with EU data-protection standards, but the European Commission is not in the position to make any individual

exemptions to companies. In response, the US Department of Commerce has developed the so-called 'Safe harbour privacy principles' that could be used by US organisations receiving personal data from the EU. The aim is to provide the 'adequate' level of privacy protection required by the EU directive. Compliance with the principles, which were issued as a draft during 1999, is purely voluntary and self-certified.

In Canada, a privacy law was introduced in direct response to the EU directive. The draft law was based on an industry standard developed by the Canadian Standards Association, which, in turn, was based on OECD guidelines. While a first attempt to get approval in Parliament failed, a revised draft passed the House of Commons and was on the agenda in the Senate in December 1999.

On 16 December, the EU and the Government of Canada issued a joint statement in Ottawa, underlining common positions on electronic commerce in the global information society. Regarding privacy, both see the need for legislative frameworks for the protection of privacy and personal information. The national frameworks should be complemented by standards at the international level.

1.3.2. Taxation

Taxes have an impact on Internet commerce. In the United States, people who live in locations with high sales taxes are significantly more likely to buy things over the Internet. The application of normal taxes to Internet transactions could reduce online sales by 30 % (Goolsbee 1999). These findings have particular significance for the United States where sales taxes are the affair of nearly 7500 state and local jurisdictions (Brown 2000).

The United States has adopted an Internet Tax Freedom Act which effectively imposes a national moratorium on the introduction of new taxation before 2001. Congress has set up an Advisory Commission on Electronic Commerce (ACEC) to study the effects of e-commerce on bricks-and-mortar retail businesses and the ability of authorities to collect applicable taxes on Internet sales. Some advocates of electronic business are arguing in favour of complete freedom from sales taxes. It is unlikely that the United States will follow this recommendation, but, if it does, this will obviously have far-reaching consequences.

EU citizens are subject to value added tax in any EU country in which they make a purchase. There is currently little information on the impact of sales taxes on EU consumers' decisions to buy outside the EU. The Institute of Directors, an association of British industrial leaders, has estimated that the UK inland revenue alone could lose up to GBP 10 billion in taxes due to downloads of music and software, pointing out that it will be especially tricky to apply VAT to consumer purchases.

International bodies have begun to concern themselves with the issue of taxation of e-commerce. Among these have been the OECD and the World Trade Organisation (WTO).

In 1998, the OECD's Committee on Fiscal Affairs (CFA) published a recommendation on principles of taxation of electronic commerce. The guiding principle is that taxation should be fair and predictable. It should not distort or impede the conduct of business, but ensure fair competition. The CFA recommended that governments should apply the same principles to e-commerce that they have already adopted for conventional commerce. There are five key criteria for the evaluation of tax systems (OECD 1998).

- Neutrality: applicable taxes should not influence business decisions.
- Efficiency: 'compliance costs for taxpayers and administration costs for the tax authorities should be minimised as far as possible'.
- Certainty and simplicity: taxpayers should be able to anticipate in advance the tax implications of a transaction.
- Effectiveness and fairness: the potential for evasion and avoidance should be minimised and counteracting measures should be proportionate to the risks involved.
- Flexibility: the ability to adapt to new technological and commercial developments.

According to the OECD, consumption taxes require the most immediate attention. There is widespread international agreement that consumption should be taxed according to the jurisdiction of the country where it takes place. Moreover, digitised products should not be treated similarly as ordinary goods of consumption.

The OECD points out that the impacts of taxation systems on small and medium-sized enterprises (SMEs) engaged in electronic commerce require close attention 'both because businesses in this sector of the economy may greatly contribute to economic growth through electronic commerce and because it may be the first time many of these businesses may find themselves operating in the comparatively more complex international taxation environment'. However, it should also be pointed out that small enterprises engaged in international mail-order business have existed for many years, and it is possible to learn from the experience gathered in this sector. In view of the expectations on the growth of electronic commerce, the volume of this kind of business might multiply making it an issue requiring more attention than in the past.

If they are fully effective, the taxation principles outlined by the OECD would ensure that competition in e-commerce takes place at the level of prices before consumer taxes. This depends largely on the implementation of national systems of tax enforcement. Since making taxation systems totally effective is likely to involve costs outweighing their benefits, a number of customers in each country might still be attracted to e-commerce by the chance that their purchases will slip through the system.

Non-physical goods pose new problems with regard to taxation, since transactions involving such goods are largely undetectable and since they can substitute tangible goods, as can happen in the case of software and music. While CDs storing music and computer programmes are subject to taxation, the implementation of the OECD's recommendation on exemption of digital products from consumption taxes could

distort competition. In February 2000, the European Commission announced its intention to propose a service tax on downloads, such as music, software or video. The implementation of such a tax poses enormous problems for its administration and execution.

1.4. Experience with business-to-consumer e-commerce

Consumer surveys during 1999 in both the United States and Europe revealed quite similar experiences with online shopping. A considerable minority of buyers experienced the same kind of problems, such as goods failing to arrive despite being billed or even having been paid for in more than half of the cases concerned. A major problem was the lack of customer service, and, in some cases, the necessary information on how to establish contact was not provided. Ordering goods was not a simple matter, since individual surveys of even top-ranking sites reported that up to 40 % of attempted purchases failed. The failure rate in locating a certain good or service from the online catalogues was even higher at well over 50 %. Among the frequent shortcomings were poor web design, long delivery times and insufficient thought given to logistics, as well as a lack of availability of items displayed. The average elderly home PC might be technically challenged by e-commerce solutions based on state-of-the-art technology.

It is particularly revealing that a mid-1999 survey found that customers preferred shopping from printed mail-order catalogues to online shopping. This indicates that at least in the case of tangible goods merchants having multiple sales channels have better long-term prospects than those relying exclusively on the web. A long-term US panel survey shows that consumers who had dropped out of e-commerce had increased paper catalogue orders by as much as 20 %. The decrease in paper-based catalogue orders for new e-commerce customers was 18 %. (Lohse et al. 1999.) These findings confirm that e-commerce is principally a new channel for mail-order retail.

Experienced Internet users rank convenience, time savings and site security as more important factors in online purchasing decisions than low prices. Apart from these, the main incentive to use web stores is to avoid overcrowded stores, in particular during peak shopping periods.

Many consumers are being disappointed by reality. During peak periods, even large sites are virtually inaccessible due to heavy traffic. The sellers often have limited inventories, although their presentations, based on catalogues compiled from distributor information, suggest that the range of available products is very large. Moreover, catalogues frequently contain items that have been discontinued. Even large sites may have only the most popular items immediately available. Items not in stock have to be ordered from distributors or even the manufacturers, and this can take time. Any advantages e-commerce might have had over conventional mail order can be reduced by such factors. Ordinary mail orders might emerge as less disappointing since customers are used to delays, while e-commerce involves expectations of almost instant gratification. For intangible goods and services, these expectations can be fulfilled. However, e-businesses can take advantage of

computerised storage management systems and display information on the available numbers of each individual good. Information on the position of each ordered good in the logistic chain of distribution can also be supplied to the customer.

Have the established players missed the boat?

It has been said that many of the established brand-name owners have been holding back their commitment to e-commerce to see how it develops and make their own entry at a strategically critical moment. Although much is to be said for learning from the mistakes of others, the question is whether waiting too long will result in a permanent loss of market shares as newcomers entering the fray as pure 'dot-coms' establish brand names of their own.

A case in point is the success of Amazon in establishing itself as the leading online bookstore against, somewhat belated, competition from established players such as Barnes and Noble, Borders or Bertelsmann. It may be contended that selling books was an obvious winner from the start, since mail-order book sales have traditionally accounted for a large share of retail revenue. In Germany, the figure is 25 % against an average 6 % share of mail order in total retail revenue (cf. Riehm 1999).

By establishing a brand name as a bookseller, Amazon, which is frequently billed as the 'poster child of e-commerce', has been able to expand its business into other areas of e-commerce. Its founder and Chief Executive Officer, Jeffrey Bezos, was elected 'Person of the Year' by *Time Magazine* in 1999. Despite the fact that the company has reported losses at the close of each quarter, it has received favourable and even enthusiastic evaluations from prominent market analysts. The company has announced that it expects to make a profit on its oldest product lines — books, music and videos — by the end of 2000.

In other branches, where conditions are less favourable for mail order, such as selling toys, the dot-coms have recently lost market shares to established merchants from the bricks-and-mortar world as these have increased their own e-commerce activities. In early 2000, there were signs that even some of the established dot-coms were short of cash (Dembeck 2000).

1.4.1. Payment systems

According to recent ESTO research (Böhle et al. 1999), a lack of suitable payment systems is not a major barrier to e-commerce at present. International payments can generally be accomplished by using credit cards, and domestic payments can be carried out with the help of payment mechanisms familiar from traditional forms of transactions. There are indications, however, that the absence of suitable payment and delivery systems means that very few low-value purchases are made on the web. This could become an obstacle to the growth of sales of intangible goods and services.

Since there are several alternative solutions vying for the small-value payments segment and none is an obvious winner, a major challenge is to create an

infrastructure which permits the interoperability of all relevant solutions. Several payment systems for use on the Internet could coexist fulfilling different needs. As regards standards, it is vital to distinguish payment products from the payment infrastructure. At the level of payment, infrastructure interoperability is the main aim and cooperation the way to reach it. At the level of payment products and services, competition is desired. Some compare the situation to the deregulated telecommunications market, where any company fulfilling certain basic requirements has free access to the infrastructure.

An interoperable infrastructure has significance with respect to European integration: people expect all familiar payment instruments to work throughout the European monetary union irrespective of national borders. To fulfil these expectations is more a political or psychological task than a short-term economic necessity. Removing obstacles could also improve European opportunities in electronic commerce.

The development of the common electronic purse specifications (CEPS) aims at enabling the interoperability of electronic purse schemes worldwide. In December 1999, a specification defining the architecture of multiple-application acceptance terminals using purchase secure application modules (PSAMs) was announced. The terminal architecture for PSAM applications will support CEPS-based electronic purses as well as EMV debit and credit cards both at physical terminals and in open environments such as the Internet.

In early 1999, major companies specialising in chip-card-based payment systems agreed to develop a pan-European standard for chip-card readers. The work will be carried out within the framework of the European Commission-supported Finread (‘Financial transactional IC card reader’) project, which is itself a part of the ISIS (‘Information society initiative for standardisation’) programme. The resulting standard should permit the use of not only EMV standard cards, but also important national cards not complying with the EMV standard, such as the French Carte Bancaire. The readers should also be suitable for use as an interface to Secure Electronic Transaction (SET) systems.

1.5. Conclusion

Although Europe is frequently described as being behind its main competitors in the field of electronic commerce, this certainly does not apply to the whole of Europe. In particular, the Nordic countries have almost similar participation rates as the United States both in e-commerce and Internet use. While there are countries in Europe which are far behind the United States and the leading countries in Europe, measures such as the e-Europe initiative can change this situation.

However, Internet use and e-commerce are not ends in themselves: citizens will only make use of them if they provide sufficient benefits and access to worthwhile products, services and information. The possibility to indulge in e-commerce is rarely a principal motive for citizens to go online.

While there have been spectacular success stories involving pure dot-com companies in the business-to-consumer sector during the past five years, it is unlikely that the next few years will see the emergence of a new 'Amazon' in Europe or elsewhere. Recent experience has shown that start-ups in the area of pure electronic commerce are encountering problems that could discourage their customers from repeating purchases. The result might be that consumers return to the trusted brand names of the past, for which electronic commerce is but one of several sales channels. Most predictions foresee that pure play e-commerce firms will also have to establish a presence in the bricks-and-mortar world. Large European bricks-and-mortar companies can exploit in e-commerce their considerable experience and competence in dealing with matters related to language, culture, logistics, regulatory frameworks, etc.

One of the main reasons why small manufacturers set up sites on the web is that they lack conventional distribution channels. Some manufacturers will try to distribute their own products in order to save costs. This would be comparable to factory outlets that offer brand-name products at lower than retail prices. Some e-commerce sites will continue to obtain discounts for their customers through pooling orders. A segment of consumers with the means to access the necessary information will benefit from lower prices obtained by these means.

The crucial factors for e-commerce at present are consumer confidence, data protection and consumer rights. Past experience has shown that merchants tend to underestimate the importance of such matters and that guidelines for adequate transparency are required. A combination of self-regulation and a light regulatory framework could afford adequate protection.

While there has been a great deal of activity and discussion on both sides of the Atlantic concerning Internet taxation, it is unlikely that electronic commerce will be exempted from sales taxes or VAT in the long run. Much of the apparent controversy in this field is based on misapprehension. If the expected increase in cross-border e-commerce of intangibles emerges, the issue of implementation of taxation principles will gain increasing significance. Any taxation of intangibles will pose enormous problems for its administration and execution.

Payment systems are currently no real barrier to electronic commerce, although there is some need for low-value payment schemes. In the national context, which at present still accounts for the bulk of e-commerce, national 'access products' are also finding use on the Internet. The completion of the single market should gradually lead to an increase in cross-border electronic commerce within the EU, increasing the demand for suitable payment mechanisms. Alternatives to credit cards could lower costs for consumers and merchants. In this segment, there is an opportunity for smart-card technology where Europe has a strong position in the world. The use of smart cards on the Internet and at points of sale would, however, require a worldwide infrastructure to ensure interoperability. There are European initiatives in this direction.

Europe has particular strengths in the newly emerging mobile e-commerce, 'm-commerce', that relies mainly on hooking up mobile telephones with smart cards.

Success in this field depends on the available content and services, and again intangible goods and services seem to have the best chances of success.

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2. DNA diagnostics: prospects in research and healthcare

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Summary

Methods of DNA diagnostics are at present applied mainly in biomedical research, but in the future they will provide powerful tools for healthcare applications as well. In healthcare, these methods will be used to diagnose not only hereditary conditions, but also infectious diseases and cancers. DNA diagnostics will make it possible to differentiate accurately between various subtypes of medical conditions and diverse strains of infectious agents. Moreover, it is expected that as a clinical tool DNA diagnostics will be rapid and inexpensive. In the long run, it could transform medical practice, as treatments can be tailored to yield the best possible results in each individual condition. Meanwhile, in biomedical research the methods of DNA diagnostics are enhancing scientists' understanding of the causes and consequences of medical conditions. DNA chips have already been eagerly adopted in drug research. As DNA diagnostics is expected to become the basis of a great number of research and business opportunities, the field has to be given close attention in European research and innovation policy.

2.1. Introduction

DNA diagnostics is one of the most rapidly evolving fields of biomedical research. It is closely related to genetic testing of hereditary conditions. Genetic tests are used to confirm diagnoses when individuals have already developed a disease, to anticipate risks of hereditary diseases in healthy individuals, and to predict the risk of having a child with an inherited disorder. The application scope of DNA diagnostics is much wider than hereditary diseases. This is because the interaction of genes underpins all physiological processes — in sickness and in health.

In the future, DNA diagnostics will also be applied to the diagnosis of non-hereditary diseases such as cancers and infectious diseases. In cancers, abnormal cells have undergone genetic mutations that let them proliferate, leading to tumours and metastases. Such mutations can be detected and analysed with the help of methods used in DNA diagnostics. Similarly, bacteria and viruses involved in infectious diseases can be detected and identified on the basis of their DNA and RNA sequences. As a method, DNA diagnostics is very accurate, and in the future it is expected to facilitate not only the identification of diseases, but also the tailoring of medications according to the unique genetic make-ups of individuals so that the best possible efficacy can be achieved.

DNA diagnostics is a subfield of medical diagnostics and can be defined as the study and application of methods in which DNA and RNA sequences are used in identifying the causes of various medical conditions. The best illustration of the promise of DNA diagnostics is the DNA chip, a piece of glass or plastic on which strings of DNA are attached. Each string can bind a complementary string from a sample and the chip reveals which particular genes and gene variations are present in the sample. DNA chips range from cheap devices that can be built in almost every laboratory to complex commercial microarray systems intended for pharmaceutical research. The latter comprise chips with hundreds of thousands of DNA strings as well as computerised analysis systems which are needed to interpret the results. At present, DNA chips are used for research purposes, but inevitably — after passing due regulatory approval processes — they will find their way into clinical diagnostics of human diseases.

DNA chips are just one of the commercial opportunities that are emerging in DNA diagnostics. Recent developments in medical DNA diagnostics illustrate the future clinical potential of the field.

- Nucleid acid testing is emerging as a very reliable method for detecting HIV and hepatitis viruses in donated blood. In a German study, the method detected viruses from samples that otherwise would have been classified as safe — about one case in every 300 000 donations. Moreover, the new method would allow the reduction of the quarantine period for fresh plasma from six months to about four weeks. (Roth et al. 1999.)

- A DNA chip has been developed to identify accurately and rapidly which particular strain of the tuberculosis bacterium is affecting a patient. After the diagnosis, doctors can prescribe antibiotics to which the strain is not resistant. The DNA chip has been developed by the US Department of Energy's Argonne National Laboratory and the Engelhardt Institute of Molecular Biology of the Russian Academy of Sciences. Mass production of the DNA chip is possible. (Quan 1999.)

- The potential of DNA diagnostics in discovering hereditary predispositions to diseases was demonstrated in a study which targeted heart disease. Variations of 70 genes that are suspected to be involved in the disease were attached on a probe. If individuals participating in the study had the corresponding genetic alleles, their dye-labelled DNA samples coloured the probe, forming strands. The pattern of strands on the probe told which beneficial and risky gene variations each individual carries. (Cheng et al. 1999.)

- A new method could significantly improve the diagnosis of mutations responsible for most hereditary cancers, such as retinoblastoma, hereditary breast cancer, and hereditary colon cancer. The advance will also improve testing for other diseases that run in families, as it eliminates the problem caused by the fact that people carry two copies of each gene. A normal gene inherited from one parent can no longer mask a defective gene inherited from the other. (Yan et al. 2000.)

- In many diseases, early diagnosis is a key to successful treatment, and this does not concern only human diseases. A DNA chip is being developed in the United States to detect the presence of yeasts in wine samples. Rapid diagnosis of wine-spoiling yeasts is expected to benefit the wine industry. (Hardin 1999.)

While we shall have to wait a few years for practical clinical applications of DNA diagnostics, the method already has an increasing significance in laboratories specialising in biological and biomedical research. DNA chips can be used to reveal the functions of genes discovered in genome mapping projects. Drug development efforts will be greatly facilitated as the tools of DNA diagnostics make it possible to understand genetic and molecular details of many medical conditions much more accurately than now. It is expected that new subtypes of known diseases will be recognised, and treatments will have to be modified accordingly.

Recent discoveries related to research applications of DNA diagnostics include the following.

- Detailed molecular portraits of a form of lymphoma obtained by DNA chip technology have revealed that there are at least two distinct forms of this cancer. Conventional research methods have not been able to differentiate between the two forms, but it has been observed that while 40 % of cases respond well to existing treatments, most patients succumb quickly to the disease. The new finding is crucial for the development of new medications. (Alizadeh et al. 2000.)

- What happens when a cell is invaded by a virus? In a recent study carried out with a DNA microarray system, it was discovered that HIV alters the way genes function within three days of exposure. Genes involved in T-cell signalling, protein transport and transcriptional regulation were among those first affected by the AIDS virus. (Geiss et al. 2000.)

- DNA microarray systems reveal which genes are activated by particular diseases and medical substances. Drug developers can compare how thousands of genes are expressed in normal and diseased tissues and can see which genes are activated by a particular drug. If a tested molecule shows a response pattern that is associated with toxicity, the molecule can be modified or dropped. The speeding-up of toxicity tests is of great significance in itself, as thousands of compounds have to be screened to find promising leads. In addition, DNA microarray systems show whether the lead compounds activate genes that are important for a particular medical condition, again speeding up the process of drug discovery. (Debouck and Goodfellow 1999.)

While the scientific value of DNA microarray systems has already been recognised in biological research and drug development, the technology is still young and at a rapid phase of development. This is why it can be expected that over the next few years increasingly convenient and powerful research devices will be developed by companies specialising in supplying DNA research systems. The convenience of DNA chip technology will improve, as it will become possible for research laboratories to produce rapidly chips for their own use. At present, it can take months to have a microarray chip manufactured by a specialised company, and the cost is high (thousands of euro). (Singh-Gasson et al. 1999.)

2.2. Technological basis of DNA diagnostics

DNA diagnostics relies mainly on three fields of research. Genome research produces data on gene sequences, bioinformatics is required in storing and analysing data on gene sequences, and, finally, special technologies are applied in the design and manufacture of DNA chips. Success in these areas determines the prospects for DNA diagnostics and this is why these fields deserve a closer look.

2.2.1. Genome sequencing

The Human genome project (HGP), which began in October 1990, is an international effort to discover the complete DNA sequence of the human genome. The sequence can be understood as a series of big books written using only four letters. When completed, the HGP will show the complete text of the human genome. It is estimated that the human DNA sequence contains about 80 000 genes — each of them a recipe for the production of a specific protein. The discovery of the exact function of each gene (functional genomics) is a daunting task in which DNA chips are expected to play an important part.

Over the last few years, technological advances have speeded up the sequencing process by a factor of about 100. In October 1999, Dr Francis Collins, Director of the US National Human Genome Research Institute, announced that the completion of the genome mapping effort should be expected for 2002 or 2003 (Collins 1999a). In June 2000, leaders of the HGP and representatives of the biotechnology company Celera announced the completion of a "working draft" reference DNA sequence of the human genome. The attainment provides scientists world-wide with an itinerary to approximately 90% of genes on every chromosome. All HGP data can be freely downloaded on the Internet.

The improvements that have allowed the acceleration include both technical advances and organisational improvements. Technical advances have been achieved in capillary sequencers and automation. The project is carried out using bacterial artificial chromosome (BAC) methodology. BACs are large segments of DNA, between 100 000 and 200 000 bases long, that can be cloned from human and other species into bacterial DNA. The method has been continuously improved, and it has become possible to study longer sequences at a higher throughput rate. Confidence in the achievement of the goals of the HGP has been raised by the completion of the DNA sequence of chromosome 22, the smallest chromosome apart from the male Y chromosome, and the acquisition of DNA sequences of important model organisms such as *Caenorhabditis elegans*.

2.2.2. Bioinformatics

Genome sequencing efforts produce huge amounts of data that can be stored and analysed only by using computerised methods. These methods constitute bioinformatics or computational biology. They range from automated acquisition of data to processing, storage, distribution, analysis and interpretation of data. In addition to DNA sequences, biological databases contain information on gene functions, proteins, and three-dimensional structures of molecules. Most of the information contained in databanks has been obtained from publicly funded research and is deposited in public databanks that can be accessed via the Internet.

The development and application of software used in accessing and analysing data is a crucial task for bioinformatics. When a novel gene sequence emerges from genome projects, genes containing similar sequences can be located with the help of appropriate software. Similarities with a sequence in the database often help to predict properties and hence the function of the new gene with considerable probability. If the search for similarities is not successful, more sophisticated approaches such as pattern searching can be applied.

Fully-fledged DNA diagnostic systems of the future are expected to include not only tools for detecting DNA variations, but also efficient software to interpret results. The diagnostic potential of combining DNA chips and software was illustrated in a recent study on two forms of leukaemia. The treatments for acute myeloid leukaemia (AML) and acute lymphoblastic leukaemia (ALL) are quite different, but differentiating between the two is difficult and requires complex and time-consuming tests. In one study, a DNA chip containing samples from more than 6000 genes was used as an

experimental tool to study samples from leukaemia patients. The findings were classified by using software that emulates neural networks and produces mappings that are known as self-organising maps. The software method has great potential because it yields practical results without requiring detailed causative analysis and modelling. The mappings of the two forms of leukaemia turned out to be so different from each other that it will be possible to use the DNA chip and software as a single test in differentiating between the two diseases. As a result, in the future obtaining an accurate diagnosis should be less costly and time-consuming than it is today. (Golub et al. 1999.)

2.2.3. DNA chip technology

DNA microarray technology originates from a method developed by the British scientist, Edwin Southern, in 1975. The method is known as Southern blotting. In it, fragments of DNA from a sample attach themselves (hybridise) to their complements that have been fixed on a support membrane such as nylon or nitrocellulose paper. Later, the method was extended to the detection of RNA fragments (Northern blotting) and to proteins (Western blotting). Similar extensions of the DNA microarray technology are emerging, indicating that it will be possible to develop arrays that collect information not only on DNA, but also on proteins and antibodies (Ge 2000).

DNA can be compared to a twisted ladder, with rungs consisting of pairs of four chemicals (bases) marked by the letters A, T, G and C. If you cut the ladder in two in the middle of each rung and fix the half-ladder so that it stands on a surface, you have an image of a DNA probe on a DNA chip. Each probe can be complemented only with a particular sequence that completely matches it, since of the four chemicals A binds only to T and G only to C and vice versa, forming base pairs. The process, in which the DNA sequence of a probe combines with its complement from a sample to form a full DNA ladder, is known as hybridisation.

DNA chips are small pieces of glass or plastic on which DNA strings have been attached. Short strings (oligonucleotides) can be synthesised on the chip by using photolithographic techniques resembling those used in the manufacture of silicon chips. DNA chips can contain hundreds of thousands of DNA probes packed very densely on the chip. Such chips are known as microarrays. The advantages of DNA microarrays over Southern blotting are the large number of DNA probes on the chip, the speed at which tests can be performed, and the small size of the sample that is required for testing. For specific requirements, it is possible to prepare customised chips which contain relatively few but long DNA probes.

Before being placed into contact with a DNA chip, a sample is labelled with a fluorescent or radioactive marker substance. During the test, DNA strings in the sample attach themselves to their complements on the chip carrying the label substance with them. Photo analysis of the surface of the chips reveals which of the original DNA probes on the chip have acquired complementary DNA from the sample. As the order of the original DNA strings is known with precision, the pattern on the chip tells what kinds of DNA fragments the sample contained.

Table 1 summarises the main constituent elements and applications of the DNA array technology. It has to be kept in mind that DNA chips include both the high-density microarrays manufactured by using sophisticated industrial technologies, as well as simple chips prepared by researchers themselves for their own research applications.

Table 1: Constituents and applications of DNA array technology

Constituents	Applications
Clone sets	Contain a large number of expressed sequences of one organism and can be used, for instance, to identify the presence of an infectious agent
Filter arrays	Are somewhat cheaper than glass-based arrays, and can be handled with less specialised equipment; filters contain a specific DNA library or can be prepared by researchers themselves
High-density microarrays	High-density microarrays include fragments of large numbers of genes, and are sold in combination with specialised equipment and software

2.3. DNA diagnostics in medical practice

At present, about 4000 hereditary diseases are known to be caused by a change (mutation) in the code of a single gene. In addition to these monogenic diseases, there are many medical conditions which are suspected to involve changes in two or more genes. Even this does not exhaustively cover the health impact of genetic variations. The development of medical conditions which can be traced mainly to environmental causes may also be influenced by genetic factors. What is also important is that often the reason why some pharmaceuticals are exceptionally beneficial or have bad side-effects for some patients is that these patients have some particular genetic features. Only recently has it been discovered that the reason why aspirin is very effective in protecting some people from heart attacks is that a specific gene variation related to their blood-clotting platelets makes them 10 times more sensitive to the anticlotting effect of aspirin than individuals who do not have the gene variation. (Cooke et al. 1998.)

It will be quite some time before full advantage can be taken of the methods of DNA diagnostics in medical practice. Despite recent advances, the methods are far from perfect and not yet cost-effective in clinical settings. Practical diagnostic applications of DNA microarrays are not yet available. Moreover, pharmaceutical companies have not yet been able to apply methods based on DNA diagnostics in drug development, and this is why the concept of medications utilising genetic differences between individuals is at an early stage of development.

Combining pharmaceutical treatments with accurate and reliable methods of DNA diagnostics may give a new chance to drug compounds that have been discarded in the past because they have caused harmful side-effects in a small number of people. It

is possible that proper DNA diagnostic tests can reveal to whom such drugs can be administered without any risk.

At present, more than 550 genetic tests are being used in the diagnosis of disease (Collins 1999b). In addition, there are tests that can identify individuals having a high risk of developing medical problems such as glaucoma or colon cancer. Such tests are particularly valuable in conditions in which preventive measures are available. Table 2 gives an overview of current DNA diagnostic methods.

Table 2: Current methods of DNA diagnostics

Mutation screening technology	Description	Use and development
Allele-specific oligonucleotide blot hybridisation (ASO)	Labelled nucleotides hybridise to a specific sequence if a certain mutation is present	Precursor for the DNA array technology
Oligonucleotide-ligation assay (OLA)	A hybridisation technique in which nucleotides having all possible one-point mutations are produced to be used as probes	Relatively strong but complicated method to detect single-point mutations
Padlock probe	Variation of OLA where a specific cleavage is used to produce a robust circular bond	Is being developed for application on solid arrays
Solid state micro sequencing	Complementary strands and labelled nucleotides are used to detect point mutations	Used to scan larger populations for heritable diseases

Source: van Ommen et al. (1999).

The Human genome project largely ignores genetic differences between individuals. If, at a certain location of a sequence, there are differences between genomes used in the project, the position is filled on the basis of the majority principle, producing what is known as a consensus sequence. As the work of the HGP has progressed, the interest in DNA variations between individuals has grown. Deviations that involve only a single base are known to cause a few hereditary diseases, such as sickle-cell anaemia.

Single-base variations that can be found in at least 1 % of a population are called single nucleotide polymorphisms (SNPs). It is estimated that there are at least 200 000 SNPs in the protein-expressing regions of the genome of a typical individual, or perhaps between 0.5 and 10 SNPs per 1000 positions along the DNA chain. SNPs are thought to be responsible for most of the genetic differences between individuals. If a particular drug is either particularly well suited to a group of patients or has strong adverse effects in a few people, the reason may well lie in SNPs. SNPs can also cause susceptibility to certain diseases. For these reasons, pharmaceutical companies have been enthusiastic about DNA chips, as one of their possible uses is discovering and diagnosing SNPs among human populations. Efforts to develop catalogues of SNPs

have been launched both by publicly funded research organisations and by pharmaceutical companies. A consortium of 10 companies has promised to present the results of its SNP research in the public domain. (Marshall 1999.)

Methods that can be used to detect SNPs are improving rapidly, as are methods that apply information on SNPs to diagnose harmful mutations or use SNPs for other purposes. At the same time, it is becoming possible to combine DNA chip technologies with methods using miniaturised analysers known as laboratories-on-a-chip. In 1999, a group of researchers designed a customisable rapid assay for SNP detection based on a silicon microchip equipped with electronic circuitry. Several processing steps of DNA samples are carried out on the microchip before the samples end up on electrodes that act as test sites, where fluorescently labelled DNA reporter probes are identified. (Gilles et al. 1999.) Such miniaturised systems applying DNA technologies are likely to be available, in due course, for doctors at their premises for rapid and highly automated DNA tests.

2.4. The consequences of DNA diagnostics for the health sector

In the long run, DNA diagnostics can be expected to become a normal part of the arsenal of diagnostic tests available in hospitals. In central laboratories, simultaneous testing of large numbers of DNA samples will become a daily practice. More limited tests will be carried out by doctors in their offices to find out if their patients are sensitive to specific therapeutics, or to determine which particular bacterial or viral strain is the cause of an infection.

The new DNA-based diagnostic methods are not only more selective than many protein-based diagnostic methods, but also more predictive. In the future, it will be increasingly common to diagnose hereditary medical conditions and some forms of cancer before any symptoms are felt by the patient. This will allow the use of preventive measures or forms of treatment designed for the early stages of illnesses. Both these alternatives are more desirable than treatment of fully developed diseases and their after-effects, and they can also spare the resources of healthcare. However, preventive treatments will not be available for all conditions that can be diagnosed in advance. Counselling plays an important role as outlined in Table 3.

Table 3: Applications and consequences of DNA diagnostics in hereditary conditions

Nature of disorder or disease	The role of DNA diagnostics	Possible measures
Immediate hereditary or congenital disorders	Prenatal screening for disorders, parental screening	Counselling, gene therapy in some cases, and treatments
Late-onset genetic disorders	Early diagnosis, pre-symptomatic testing	Prediction, early treatment, counselling
Common disorders with a hereditary subset	Early diagnosis, predictive testing	Monitoring
Common disorders with a genetic susceptibility	Early diagnosis	Preventive measures

Source: Based on Gezondheidsraad (1998).

Table 3 shows that the consequences of new diagnostic methods will vary according to the different types of hereditary conditions involved. There are ethical issues involved when a decision has to be made as to whether and how to inform an individual that he or she has a potential to develop a disease for which there are no available treatments.

One of the policy issues regarding hereditary conditions concerns whether genetic tests are to become part of a 'standard set' of practices during pregnancy. There are both ethical and financial issues involved. There could emerge a strive for the 'perfect child', if tests on eye colour or factors related to intelligence can be developed. Prenatal testing for diseases such as cystic fibrosis is not expected to be carried out for general populations. The basis for screening individuals could be the birth of one affected child to the family. However, as soon as inexpensive prenatal screening methods for hereditary diseases become available, the demand for them can be expected to grow.

The ethical issues raised by new methods of DNA diagnostics are at the core of general concerns related to medical research and product development. The technology seems to offer potential for reducing costs and increasing efficiency. However, in some cases, the new methods could result in higher costs, as early diagnosis may lead to long and costly preventive treatments and monitoring periods. If large groups of patients were to need long-term preventive measures and monitoring, the costs to the healthcare system could be considerable. On the other hand, many individuals would be willing to pay for access to preventive programmes, and advances in medical technology could lead to the development of less expensive monitoring and medication systems that could be used in the home.

Ethical concerns are largely absent in the application of DNA diagnostics in infectious diseases and treatable cancers. In these conditions, DNA chips can be expected to improve the accuracy of diagnosis and enable selection of the most effective treatment strategies. The main concerns here are cost and competition. DNA chips are a rapidly evolving technology, and it is reasonable to expect that significant cost reductions will be achieved. However, at present, the high-density DNA microarray technology is dominated by a single US company, Affymetrix Inc.

2.5. Conclusion

A general conclusion that has often been made is that in life sciences the scientific expertise in Europe is rather good, but Europe lacks the commercial culture that is one of the main driving forces of the field in the United States. While the United States has taken the lead in high-density DNA microarrays, the technology is still at an early stage of development and will allow the entry of new commercial competitors having viable ideas. The economic potential of the field is great, and it has been suggested that future revenues from the sales of biochips could rival those from computer chips (Schena et al. 1998).

As long as the results of genome projects remain public, all can profit from them. For European scientists and companies, there are still technological opportunities available for entering the field of DNA diagnostics. European authorities should not only defend publication of genome data in the public domain, but also encourage RTD efforts in the field of DNA diagnostics.

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3. Electricity markets: competition and renewable sources

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Summary

Competition is intensifying in the European electricity market. How will this affect the rate at which renewable energy technologies are adopted in Europe? Europe has committed itself to the liberalisation of the electricity market, but at the same time the European Commission has suggested that the share of renewable energy sources should be raised from the present level of 6 % to 12 % by the year 2010. Moreover, clean energy sources play an important role in the international efforts to stabilise the global climate. This chapter analyses possibilities and barriers for renewable energy sources in the new competitive environment. A number of different schemes for promoting renewables are discussed, and experiences from different EU countries are compared.

3.1. Introduction

Deregulating market forces is the trend of today. On 19 February 1999, the largest European industrial consumers of electricity gained the freedom to choose their suppliers from anywhere in the EU (Barnard 1999). On that day, the directive deregulating the European electricity market came into effect. In the United States, pressure for similar federal legislative action was increasing during 1999, and more than 20 states had already taken action to increase competition in energy production and distribution. However, in California and Massachusetts, criticism against deregulation ran so high that some of the measures already carried out were almost overturned in 1999 state referendums. In 1999, energy deregulation was also a hot topic in other parts of the world. Numerous countries were privatising or restructuring their energy industries.

The strive for sustainable solutions is the other side of the energy equation. The concept of 'sustainable development' got worldwide attention after the publication of the so-called 'Brundtland report' (World Commission on Environment and Development 1987). The concept was formally introduced into international politics in the Framework Convention on Climate Change signed by 155 nations at the UN conference in Rio de Janeiro in 1992. It was realised that the energy sector and its contribution to the greenhouse effect should play a major role in the policy for sustainable environmental development. It is interesting to note that although there has been a general scepticism in many industrial sectors in relation to the consequences of the greenhouse effect and the concern of global climate changes, now these problems are taken seriously by at least one commercial sector, namely the insurance companies. The actual insurance pay-outs due to natural disasters (accumulated per decade) has increased steadily from less than USD 4 billion in the 1960s to more than USD 70 billion in the 1990s (Streiff 2000).

The Convention on Climate Change has been followed up by a number of conferences of parties charged with the purpose of finding operational procedures for stabilising the global climate. In Kyoto, in December 1997, agreements were reached on targets for greenhouse gas reductions for industrial nations and regions. The reductions are relative to emissions in 1990 and refer to a basket of six greenhouse gases dominated by carbon dioxide (CO_2). The targets are 8 % for the EU, 7 % for the United States, and 5.2 % on average for the industrial world; the targets should be reached by 2012. The EU members have agreed on how to distribute the targets between them. Denmark and Germany are to cut their emissions by 21 %, while at the other end of the scale Greece can increase emissions by 27 % and Portugal by 25 %.

The main solutions for reaching the targets set by the Kyoto Protocol are energy conservation and the use of renewable energy sources. In this chapter, the focus will be on the potential and implementation of renewable sources in the production of electricity. This is not meant to imply that the potential of energy conservation is less important. On the contrary, energy conservation is more cost-effective in the short run, and the two solutions should be seen as complementary to each other.

A recent policy question in the climate negotiations has been the extent of the so-called 'flexible mechanisms' including trading of CO_2 quotas and joint implementation projects. These mechanisms are especially promoted by the United States, while some European countries have warned that due to uncertainties in determining correct baselines the mechanisms may be exploited in ways which are counterproductive to the goal of reducing global greenhouse gas emissions. In order to obtain more practical experience on joint implementation, an EU project was accepted by the European Commission in 1999 concerning joint implementation projects between utilities in east and west Europe (JOINT 1999).

At present, wind power and biomass are the most important 'new' renewable sources of energy in electricity generation. Others include solar power, wave power and small-scale hydropower. Large hydroelectric installations are based on a mature and fully competitive technology, but their additional potential in Europe is limited for environmental reasons. Electricity production based on incineration of industrial and household waste and gas from refuse dumps is not usually considered to be a clean technology. Geothermal energy is environmentally friendly, but not strictly speaking a renewable energy source. Due to relatively high costs of production, wind power and other renewable sources of electricity cannot compete in a free commercial market with mature technologies such as large hydro schemes, combined cycle plants based on natural gas, or efficient coal-fired combined heat and power plants. The question is then how best to promote technical development in renewables in order to make them more competitive or how to give them economic support so that their use would become more attractive.

In the EU, there is a widespread feeling that the use of renewable energy sources should be increased while keeping the growth of energy consumption at a low level or even aiming at reducing demand. In a recent European Commission White Paper, it was suggested that by the year 2010 the share of primary energy produced from renewables should be increased from the present level of 6 % to 12 % (European Commission 1997). So far, no agreement on how this goal would be shared by the Member States has been negotiated within the EU. Individual countries have, however, published goals for increasing the use of renewable energy sources. In 1990, Denmark became the first EU country to make official commitments on targets for CO_2 reduction and the use of renewables (Danish Energy Ministry 1990). The present Danish target for renewables is that their use should reach 12 to 14 % of primary energy production by 2005 and 35 % by 2030 (Danish Ministry of the Environment and Energy 1996). The realisation of these targets is an ambitious technical, organisational and political project, which will involve radical changes in societal infrastructure.

3.2. Deregulating electricity markets in Europe

Liberalisation of electricity markets in Europe was initiated by the UK (1989) and Norway (1991), followed by Sweden (1994) and Finland (1996). Agreement on the directive specifying the rules for electricity liberalisation in the EU was reached in December 1996 by the Council of Ministers (European Communities 1997). The goal

of the directive is to achieve higher efficiency and lower consumer prices by introducing conditions of intensified commercial competition.

The following points of the directive are of special interest.

- Member States may impose on undertakings operating in the electricity sector public service obligations related to security of supply and environmental protection. In this context Member States may introduce long-term planning provisions (Article 3(2)).
- For the construction of new generating capacity, Member States may choose between an authorisation procedure and/or a tendering procedure.
- Member States shall designate transmission system operators and distribution system operators (Articles 7(1) and 10(2)).
- Debundling: integrated electricity undertakings shall, in their internal accounting, keep separate accounts for their generation, transmission and distribution activities (Article 14(3)).
- Gradual opening of electricity markets to competition from suppliers within the EU. The market should always be open to customers consuming more than 100 GWh/year (Articles 19(2) and 19(3)).

It may be noted that some EU Member States did not fully comply with the directive when it came into force on 19 February 1999, with France being an extreme example. Countries such as Denmark, Germany, the Netherlands, Sweden and the UK have opened their national markets by more than required in the directive. However, for international trade in electricity, a number of barriers, such as special transmission duties, remain. (Skytte 1999; Olsen 1998.) Table 1 shows how electricity liberalisation is expected to develop in the EU.

Table 1: Opening electricity markets to competition in the EU Member States

Country	Share of electricity markets opened to competition by December 1999	Share of liberalised electricity markets in the future (where known)
Belgium	—	35 % in 2001; 100 % in 2010
Denmark	90 %	100 % in 2003
Germany	100 %	—
Greece	—	28–30 % in 2001
Spain	46 %	100 % in 2004
France	20 %	—
Ireland	—	28 % in 2002
Italy	30 %	—
Luxembourg	45 %	—
Netherlands	33 %	100 % in 2003
Austria	27 %	50 % in 2003
Portugal	26 %	—
Finland	100 %	—
Sweden	100 %	—
UK	100 %	—

Source: European Commission.

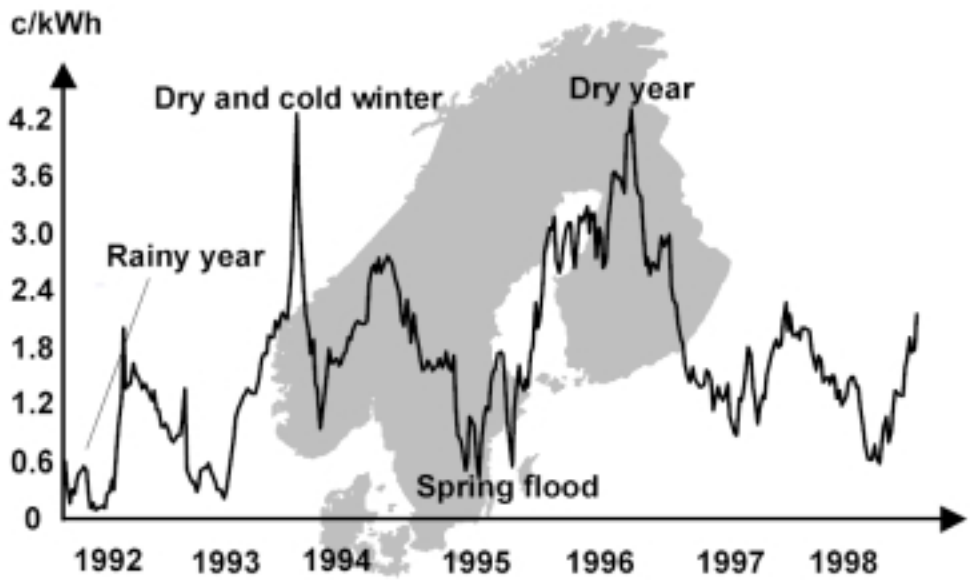
The directive does not give high priority to energy conservation and renewable energy sources. On the contrary, there is an apparent conflict between the commercial goal of profit maximisation that is often based on a time horizon of 5 to 10 years, and the need for long-term energy conservation and implementation of supply systems based on renewable sources. As a compromise, the directive gives national governments the option of introducing 'public service obligations' based on considerations of security of supply, energy quality, price and environmental protection (Article 3(2)).

3.3. Experiences of electricity trading

The first international electricity trade pool was set up by Norway in 1992 under the name Nord Pool. Nowadays, countries that are using the Nord Pool system include Denmark, Germany, Finland and Sweden. The volume of trade doubled in 1999 and reached a total value of about EUR 4.5 billion (Nord Pool 2000).

Although the experience of trade in Nord Pool is limited to less than a decade, interesting observations can already be made. One is that prices in the electricity pool have fluctuated widely as illustrated in Figure 1. It may not be correct to conclude that such fluctuations can be expected to occur in future European electricity pools, because the trade in Nord Pool is to a large extent based on electricity from Norwegian and Swedish hydropower installations, where production volumes and costs are strongly influenced by climatic variations, as can be seen in Figure 1. During dry years, the price peaks while it reaches very low levels in rainy years. Price fluctuations may become less pronounced as the traded volume increases and more electricity from thermal plants is included.

Figure 1: Price of electricity in the Nord Pool system, 1992–99 (weekly averages)

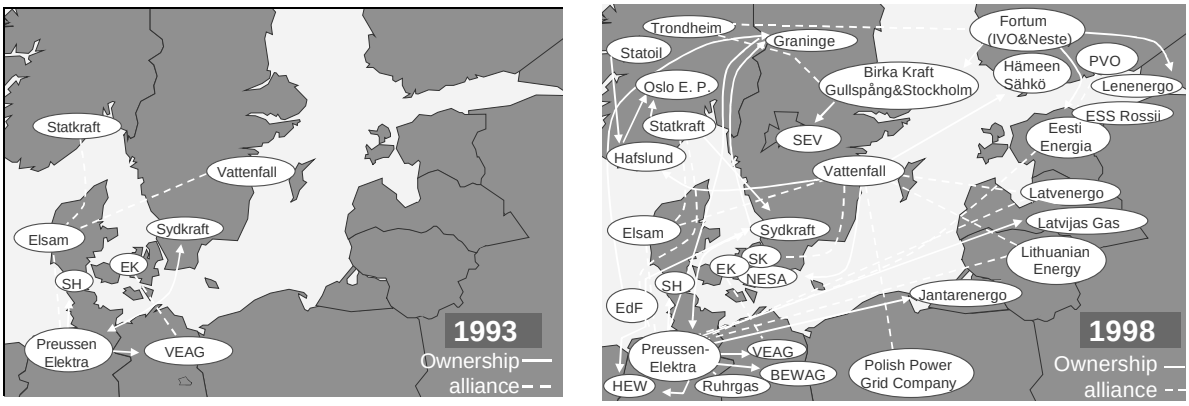


NB: c/kWh: price in eurocents per kWh.

After liberalisation, there has been a trend towards lower consumer prices. In Germany, the price for large customers dropped by more than 30 % during 1999. For instance, the regional price for PreussenElektra was DEM 0.1415/kWh in July 1999 while the price in January 2000 was down to DEM 0.1182/kWh (Dow Jones/VIK 2000). Production, transmission and distribution costs have been reduced by rationalisation in a number of different ways. However, several large utilities have announced at conferences that they can no longer afford to finance previous levels of technical research and development in a market that is now much more competitive. It is less likely that the general level of service to customers will be hurt by the intensified competition, since service in itself is an important means of competition.

Another general trend that can be traced back to market liberalisation is an acceleration of mergers and alliances between European utilities. Large electricity utilities such as the German PreussenElektra, French EdF, and Swedish Vattenfall are buying up smaller competitors and building strategic alliances. This process is so fast that is has been argued that in the end public monopolies may to a large extent be replaced by private ones. The EU directive lays down only relatively weak requirements for debundling of activities and thus allows strong concentrations of market power in the European electricity sector. An illustration of the way in which the formation of alliances and mergers has been accelerated is given in Figure 2.

Figure 2: Alliances and mergers in the European electricity sector in northern Europe, 1993 and 1998



Source: Personal communication (Pedersen 1999).

3.4. Developments in individual European countries

Liberalisation of electricity markets and the adoption of supply systems based on renewable energy sources are progressing at widely different speeds among European countries. In this section, we shall summarise the main developments in six representative EU countries. More details can be found in the final report of a recent EU project (REALM project 1999).

3.4.1. United Kingdom

The UK was the first European country to pursue wholesale liberalisation. The 1989 Electricity Act privatised and restructured the electricity industry, leading to a complete opening of the market by the end of 1998. As a result, power prices in real terms are lower than before privatisation, and the size of the workforce in the electricity industry has been decimated. There has been a great deal of takeover and merger activity in the British electricity sector, including takeovers by American and European utilities. The new vertically integrated electricity companies seek economies of scale in their nationwide competition for customers.

Renewable energy sources have been supported mainly by the 'Non-fossil fuel obligation' (NFFO) scheme. It awards fixed price contracts to producers which are selected on the basis of price competition in each category of renewable electricity production technology. The system is administered by a central agency, and the cost is recovered by a levy on electricity consumers. The mechanism has supported about 85 % of all renewable electricity generation in the UK, but the total capacity achieved amounts only to about 3 % of the UK electricity supply, a low figure in comparison with other EU countries.

The potential interest of British consumers in renewable or 'green' electricity tariffs is still unproven. Some new entrants to the green supply market have ambitious plans to expand, but the overall level of uptake is still low.

The UK national target for electricity generated by renewable energy is 10 % by the year 2010. A new Utilities Bill was published in January 2000 and is expected to be ratified by the British Parliament during the spring. According to this bill, the NFFO scheme will be abandoned and replaced by an obligation-driven market. (Houses of Parliament 2000.)

3.4.2. Austria

The legal framework for the liberalisation of the Austrian electricity market is defined in a law according to which 27 % of the market was opened to competition by 1999 and 50 % will be opened by the year 2003. By the year 2005, 3 % of electricity sold by Austrian utilities should originate from new renewables such as wind, solar power and biomass (excluding waste). Electricity distribution companies have to accept all renewable power (except hydroelectricity) produced by independent power producers at a specified feed-in tariff. Moreover, the independent producers are allowed to sell power from renewables directly to all final consumers. All power producers shall have access to the grid on equal terms.

These rules were implemented in 1999 and have brought dramatic changes to the Austrian electricity sector as utilities from France, Germany and Switzerland are attempting to penetrate the Austrian market. Electricity prices for eligible customers can be expected to converge towards the cheapest offers on the market, and it is

possible that only the most efficient Austrian producers with the highest financial reserves will survive the next five years (REALM project 1999). As a consequence, Austrian utilities are seeking strategic alliances with national and international partners, and they have been forced to reduce electricity tariffs to captive customers by about 10 %.

3.4.3. The Netherlands

In the Netherlands, an Electricity Bill enacted in 1998 liberalised the electricity market in stages. During that year, customers with an annual average power consumption of more than 2 MW were given a free choice of suppliers. The share of these customers corresponded to about 33 % of the total market. From the year 2003, all customers will be given such freedom.

A special supervisory bureau (DTE) has been set up to supervise and regulate the activities of the power grid owners whose profits are regulated. Since 1996, a number of utilities have offered customers the choice of green electricity at a surcharge that averages around EUR 0.033/kWh. The utilities guarantee that the revenue from green electricity sales will be invested in new green production capacity. This trade is controlled by independent organisations such as the World Wildlife Fund. Only a small fraction, about 40 000 households out of about 6 million, currently buy green electricity. Starting from 1999, green electricity has been made more attractive by exempting user households from the regulatory energy tax.

The Dutch Electricity Act includes an optional measure that requires final users to consume a certain amount of electricity based on renewable sources. This measure will be implemented by 2001, if the industry does not meet the required target by itself. In early 1998, EnergieNed introduced a certificate system which establishes a market for green electricity. The aim is that 1.7 TWh of electricity will be produced from renewable sources in 2000. It is expected that trading with green certificates will develop during the year 2000 when distribution companies have to meet their individual targets. Each supply company has been allotted a quota of electricity that is to be obtained from hydro, wind, solar, biomass, or gas from landfills. There is a penalty for those supply companies which fail to meet their targets for the year 2000.

In the Netherlands, the Energy Act of 1989 separated electricity distribution and production companies. Since that time, distribution companies have been obliged to accept electricity from independent producers. Moreover, large electricity users had the freedom to choose their suppliers, and distribution companies were free to purchase electricity from production companies outside their own region.

3.4.4. Denmark

The regulations for the Danish electricity sector are laid down in a new Electricity Act dating from June 1999. It opens the electricity market at a faster rate than that required by the EU directive. By January 2001, the market is to be opened to all electricity customers that consume over 1 GW a year, and, by January 2003,

liberalisation will extend to all consumers. The act makes a break with the traditional Danish non-profit-making principle, as power plants are to be operated as ordinary commercial enterprises in the future. Users of district heating are to be protected against unfair price increases. The profits of grid companies will be regulated and the majority of members of their boards will be elected by customers.

A special certificate market will be introduced for green electricity with an obligatory consumer quota. The Danish Government has specified that 20 % of the electricity demand shall be covered by renewable sources by 2003. The law also specifies that the annual CO_2 emission of utilities will be restricted to 20 million tonnes by the year 2003.

During 1999, a number of problems occurred in the transition to a more liberalised market. There were problems in financing power plants and distribution companies while they were being transformed from non-profit-making utilities to competitive free market enterprises. Special schemes were agreed by the government and the utilities in order to avoid serious economic problems. It is too early to say whether these schemes are sufficient to secure the competitiveness of the Danish electricity sector.

Other problems related to operational details of the green market where the trading of certificates was originally planned to start in January 2000. The Danish Government has now postponed the start of trading until 2002.

3.4.5. Germany

In Germany, a new Energy Act came into effect in April 1998. It obliges the operators of the electricity grid to allow transmission for all customers except in specific cases that are listed in the act. Thus the German electricity market is, in principle, fully open to competition. In contrast to most other Member States, there is no regulatory authority and no operational rules for access or tariffs. These issues were left to the industry itself.

The German electricity industry is highly integrated and is dominated by eight supra-regional utility companies that produce more than 80 % of the public supply and own about 80 % of the high-voltage grid as well as control transmission and distribution grids in their traditional supply areas. The new act does not demand unbundling or changes in network ownership or operation. In practice, the new grid access rules have turned out to be a major obstacle to real competition. Since the liberalisation, the supra-regional utilities have increased their stakes in regional and municipal utilities and have now started to merge with one another. One possible scenario for the medium term is that the industry will be concentrated into three or four blocks of utilities.

The first overall agreement on rules for grid access and tariffs was reached by the electricity industry and large industrial customers in May 1998. The agreement was heavily criticised because of a lack of transparency and practicability, high charges and tariffs that depend on distance. The next agreement is now under way and is

expected to create a more level playing field. One of the controversial questions is how to standardise load profiles and charges for typical households. Electricity prices have fallen by up to 30 % since the enactment of the new act, but the main price reductions have been given to large industrial and bundle customers. Competition in the residential sector really started only in the summer of 1999.

In the past, German utilities have not favoured renewable energy sources. In fact, they have actively opposed the Electricity Feed-In Law. A new version of this law was confirmed by the German Parliament in February 2000, but it may be contested in court by German utilities.

3.4.6. Greece

In Greece, changes in energy market legislation were not completed by the time this chapter was being written. According to a preliminary version of the new legislation, market liberalisation would be introduced in February 2001. About 450 eligible industrial customers using 2 GWh or more per year would be given the right to enter into direct trading with suppliers. The arrangement would cover about 30 % of the Greek electricity market.

It is expected that the Public Power Corporation (PPC) will be split into independent entities. The corporation will lose its exclusive right to generate electricity from conventional fuels on the mainland. The company will, however, continue to own the transmission system which will be operated by a separate and independent entity called ISO. On the Greek islands, the PPC will continue to have exclusive rights for transmission and distribution.

3.5. Promoting electricity from renewable sources

The European Commission is continuing its efforts to formulate a directive on the trade in electricity produced from renewable sources. In April 1999, the Commission published working papers on the topic (European Commission 1999a, 1999b). These papers evaluated existing subsidy schemes and systems for promoting the use of electricity from renewables in liberalised markets. In May 1999, the EU Council of Ministers requested the Commission to prepare a draft directive based on responses from the Member States. The Commission did not succeed in reaching internal agreement on a new directive before the Council met in December 1999. The Council was only given a general orientation concerning different schemes for green markets. The main focus was on systems of green certificate trading. In the following sections, the main features of different regulatory regimes are examined.

3.5.1. The feed-in system

In a feed-in system, a long-term minimum price is guaranteed for electricity obtained from renewable sources. In combination with standardised costs for grid connections

and short lead times, the pricing system has made it possible for developers to obtain easily bank financing for investments in wind power stations.

In promoting wind power, the feed-in system has been used with some variations in Denmark, Germany and Spain and has proved superior to other methods that have been tried in the EU. At the beginning of the new millennium, the installed wind power capacity was about 1700 MW in Denmark, 4500 MW in Germany and 1100 MW in Spain. The combined wind power capacity of these countries comprises around 80 % of the EU total. Countries which have used other approaches, including the UK (which has the best wind potential in Europe), have installed much lower wind power capacities. It may thus be concluded that the feed-in model has been superior to other applied models in Europe in promoting wind power.

The feed-in tariffs have usually varied between EUR 0.077 and EUR 0.093/kWh. One problem with the system is that a fixed price level does not conform to traditional market principles. The Danish Government has already taken notice of this and is preparing to replace the feed-in regime by a certificate system as mentioned earlier.

Another criticism against the feed-in model has been that the favourable tariffs have not been reduced in step with technological development. Windfall profits have been obtained by operators of the most modern wind turbines located at favourable sites. However, such problems could be overcome in several ways without abandoning the main elements of the feed-in model. The Danish Council for Sustainable Energy has proposed that tariffs should be linked to the rate at which each individual turbine generates electricity. The tariff could be reduced after a certain production (and profitability) level has been reached. An alternative solution would be to adjust the tariff for new installations at regular intervals taking into account the best technology on the market (benchmarking principle). This would also introduce an element of competition into the system. As the market share of wind power increases, the burden of the feed-in system on government finances could become unacceptable. This can be avoided by financing the system from charges levied on electricity consumers.

It is also possible to design a feed-in system in a way that gives producers relying on renewable energy sources a fixed premium on top of the market price of conventional electricity. The fixed premium per kilowatt-hour of electricity can be financed by means of a tax on all electricity consumption. Such a scheme has been used in Spain. The result is a flexible system that may include elements of market competition between traditional electricity and that based on renewables, if utilities are not obliged to accept all electricity which is produced from renewable sources. The model may also introduce competition between renewable electricity technologies at different development stages if premiums reflect differences in production costs. However, in order to make this a dynamic process, premium tariffs should be adjusted at frequent intervals to take technological development into account.

3.5.2. Quota tender system

Another approach to promote electricity from renewable sources is the quota tender system developed in the UK. In this system, calls for tenders for providing electricity

are made at intermittent intervals. Each renewable technology is given a quota, and the provider of the lowest asking price is given the contract.

The Non-Fossil Fuel Obligation (NFFO) dates from the early 1990s and so far there has been a succession of five competitive tenders in the UK. Although the scheme has resulted in reduced prices, the quantitative results have not been impressive. Less than one third of the winning bids for wind power have been realised, and the installed capacity has not reached 400 MW. This seems to be mainly due to local opposition against wind farms in scenic areas. Local ownership of wind farms and improved planning principles could reduce the problems.

The intermittent nature of the NFFO procedure is not consistent with continued and predictable sales of energy production equipment. In addition, there is uncertainty about possible shifts in political support for renewable energy sources. These problems could be counteracted by guaranteed long-term calls for tenders.

As a result of the ongoing legislative changes that have been described here, the tender system will be abandoned in the near future.

3.5.3. Green certificate markets

The aim of green certificate markets is to introduce conditions of market competition into the production of green electricity. So far, no complete agreement has been reached in the EU on the definition of renewable technologies that can be included in special green markets. A possible outcome is that the EU definition will be constrained to electricity based on wind power, photovoltaics (PVs), small hydro schemes (less than 10 MW, for instance), wave power and biomass.

A green certificate market has operated in the Netherlands since the beginning of 1998 and is supported by a voluntary consumer quota of green electricity. Electricity producers using renewable sources receive a total payment consisting of the market price of conventional electricity supplemented by the market price of the green certificate. A number of Dutch distribution companies have agreed voluntarily to fulfil a green electricity quota for the year 2000. After that, Parliament will decide whether or not to introduce an obligatory consumer quota.

So far, the system has not been able to accelerate the penetration of wind power in the Netherlands to any noticeable extent. Nonetheless, an adjusted version of the Dutch model has been adopted by the Danish Government in its new Electricity Act as discussed in Section 3.4.4. Italy and the Flemish Government in Belgium are planning to initiate certificate markets by 2001.

One of the problems of green certificate markets concerns fairness of competition between renewable technologies that are at different stages of development. If free competition between different renewable technologies is instigated today, wind power would probably sweep most of the market. Solar electricity would not have a chance, while biomass and small hydro might be competitive in special cases. Such a market situation could not be considered optimal for the long-term promotion of the total

renewable potential. One possible solution is to reserve the green market for the most mature renewable technologies and to promote other desired technologies through a quota tender model.

In a green certificate market where an obligatory consumer quota is applied, the price of green certificates can be expected to fluctuate wildly. When there is a shortage of electricity based on renewables, the price of green certificates will be very high. The price will fall to a very low value when there is a surplus. The uncertainty about the price increases the risks of investors and reduces investments in renewable technologies. The same problem of swings in market prices has been encountered with the market rules used in California (Ford 1999).

In the new Danish system, minimum and maximum prices are defined for green certificates, but it can be expected that the market price will land either at the minimum or maximum value. Investors will still face an uncertain situation. The problem can be alleviated by long-term electricity supply contracts. Another approach is to take advantage of banking and futures mechanisms.

There is increasing interest in setting up international markets for green certificates. These could help to stabilise certificate prices, while national markets are likely to remain too small for the creation of price stability. A precondition for an eventual international market is that national rules are harmonised to such an extent that unfair competition can be avoided. Complicated negotiations have to be carried out before a fair international market can be established. Negotiations have already taken place between a group of utilities from Belgium, Denmark, Germany, Italy, the Netherlands, Austria and the UK. The goal has been to set up a pilot project on international trade in green certificates (RECS 1999).

3.6. Conclusion

The extent to which electricity markets have been liberalised varies between European countries. Many countries have opened their markets at a faster pace than that required by the EU directive. The result is that consumer prices have been declining in accordance with the goal of the European Commission. In addition, mergers and alliances between European utilities have been accelerated. As a consequence, it is expected that strong business concentrations will emerge in the electricity sector and may even lead to the creation of oligopolies, whose market power should be closely monitored by the competition authorities.

In promoting the use of electricity produced from renewable energy sources, the greatest successes have been obtained by the application of the feed-in system in Denmark, Germany and Spain. Thus, if the highest priority is given to fulfilling ambitious goals for the penetration of renewable energy sources, the natural conclusion would be to rely on the feed-in model. The burden on the government budget can be reduced by sharing the premium tariff between electricity consumers, and competitive features may be introduced by using benchmarking principles.

However, the feed-in system does not fully conform to the principles of free market competition.

Several EU Member States are supporting a green certificate system with specified consumer quotas for electricity from renewable sources. The discussion in this chapter has illustrated that there are many uncertainties for investors in this system. These have to be considered in depth in order to avoid disruptions in the market. Moreover, transaction costs can be high in competitive market schemes. The creation of green markets is a very complex process. Throwing renewable technologies into an uncertain commercial market may cause serious setbacks in extending the use of clean energy sources. The problems related to market competition between technologies at different stages of development may be alleviated by combining the certificate model with a centralised tender model.

The present political trend favours the use of the commercial market as a driving force for technical change. This political preference presents a dilemma for the long-term development of clean energy sources. It is the judgment of this author and others (Illum and Müller 1998) that a cost-effective and sustainable energy solution requires comprehensive planning — and the inclusion of the transport sector — with time horizons of 30 to 50 years. This is in conflict with the characteristics of a commercial market. The planning of an energy supply system that takes a large contribution from fluctuating energy sources is a much more complex project than planning traditional energy systems based on fossil fuels. Decisions based on short-term profits may well block the least cost long-term sustainable solutions. The challenge for the proponents of market principles is to demonstrate that this dilemma can be solved in a satisfactory fashion.

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4. Fuel cells: the next few crucial years

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Summary

Changes in regulations and fluctuating prices are affecting the competitive position of clean energy sources such as fuel-cell technology. The technology seems to be on the brink of commercialisation and could be used to produce electricity with almost zero emissions. RTD policy-makers are facing the challenge of guiding the development of fuel-cell technology over a critical period during which outstanding technical problems will have to be solved. In the short term, the focus will be on reducing costs and increasing lifetimes; over the long term, there may be a need to develop new infrastructures for fuel delivery. Fortunately, efforts to improve both the technology and its commercial potential are progressing well. Fuel-cell technology is entering a crucial period in its evolution.

4.1. Introduction

In 1999, it became evident that prospects for the successful commercialisation of fuel cells were improving. Leading companies in the field invested significant amounts of money in the technology, infrastructure and applications. The question was no longer whether or not fuel cells will have a place in the energy markets of the future, but how the commercialisation process should be carried out in practice.

There is a growing expectation that the first commercial applications of fuel cells will be stationary power plants producing electricity and heat for residential or industrial use. Recent developments strengthen this expectation.

- In 1999, the German company Vaillant, one of Europe's leading manufacturers of heating appliances, entered into a cooperation arrangement with two leading US fuel-cell technology companies, Plug Power and GE Fuel Cell Systems (Vaillant 1999). Over the next few years, Vaillant is expected to test and market devices that will produce 4.5 kW of electric power and 35 kW of heat, enough for houses with 4 to 10 apartments. The expected price of the fuel-cell units is around EUR 10 000.
- The German power plant supplier, Alstom, announced in December 1998 that it is going to build Europe's first fuel-cell factory in Dresden. The plant is a joint venture with Ballard Generation Systems of Canada and will produce 250 kW fuel-cell systems based on proton exchange membrane (PEM) technology. These small power plants are particularly suited to combined heat and power (CHP) production. (Alstom 1998.)
- In the UK, National Power announced in July 1999 that it is going to build a demonstration plant using its fuel-cell-based electricity storage technology. The plant will have the capacity to store 120 MWh of electricity which is enough to supply around 10 000 domestic consumers for a day. Electricity will be stored when demand and prices are low and released during peak demand hours. The system removes the need to start generation in expensive or pollution-prone plants for short periods of time. (National Power 1999.)
- In Europe, test and demonstration fuel-cell facilities have been built partly on the basis of funding received from EU energy research programmes. The plants are located in Milan, Berlin, Wazier (France) and elsewhere in Europe. (Lequeux 1999.)

Future automotive applications of fuel cells have the potential to reduce emissions from transport. However, building infrastructures for hydrogen delivery is a tough commercial challenge. Fortunately, it may be possible to use other fuels, such as methanol or even petrol, as an alternative to hydrogen. Companies that have announced that they have plans to start manufacturing fuel-cell-powered cars around 2004–06 include DaimlerChrysler, General Motors, Ford, Mazda, Toyota, Honda and Nissan. Most of these companies rely on power systems developed by the Canadian Ballard Power Systems, a parent company of Ballard Generation Systems. In 1999,

the likelihood increased that after a few years fuel-cell-powered cars will be introduced onto the market:

- In late 1999, Ballard Power Systems completed its new Mark 900 PEM fuel-cell stack and power module. The power density of the new unit is almost 30 % higher and its weight is about 30 % lower than that of the previous model. The new unit was said to be very close to the design that will be produced in large quantities within the next few years. (H & FCL 2000.)
- DaimlerChrysler has completed its new passenger vehicle, NECAR 5, which takes advantage of Ballard's Mark 900 system (H & FCL 1999a).
- In September 1999, Ford and, in October, Toyota, Honda, Nissan and Mazda unveiled new experimental fuel-cell vehicles (H & FCL 1999b).
- Hydrogen gas stations for fuel-cell cars were launched in 1999 in Hamburg, Munich, and in Dearborn, Michigan, in the United States (H & FCL 1999c).

An interesting debate has emerged in recent times concerning which fuel-cell application area will take the lead in commercialisation. While there is considerable activity in stationary and automotive applications, some observers anticipate that small-scale portable applications have the greatest potential in the short term (Ferrara 1999). The scope for fuel cells in portable applications ranges from generator sets to power tools, telecommunications devices and computers. Interest has been stimulated, in part, by the limitations of conventional battery technology to fully deliver what users need. Fuel cells have the potential to store considerably more power per unit of weight or volume, are more environmentally friendly, and could have much longer lifetimes. Recent technological advances illustrate the potential of portable fuel-cell applications.

- A prototype hydrogen fuel cell for powering a professional video camera was developed — equivalent in size and weight to existing battery power, with more than six times greater power output for equivalent weight (H-power 1999).
- A prototype hydrogen fuel cell for providing emergency power, particularly for telecommunications equipment was developed — supplying 200 to 250 W for more than six hours, weighing 90 kg (Ishizawa et al. 1999).
- A prototype miniature methanol-powered fuel cell for mobile phones is planned to be released onto the market at the end of 2001 (Manhattan Scientifics 2000). Such a device could have an energy density 50 to 100 times that of conventional nickel–cadmium batteries. (Chase 1998.)
- In 1999, it was revealed that in US Army tests fuel cells were attractive compared with conventional batteries in missions extending beyond a day. One limiting factor, however, was the absence of appropriate sources of hydrogen. (Stephens 1999.)

The general trend in fuel cells is that the technology is migrating from the laboratory to the marketplace. The challenge for policy-makers is to provide an effective framework for commercialisation which will support European competitiveness and encourage full exploitation of environmentally desirable features of fuel-cell applications. In the following sections, we shall concentrate on the prospects of fuel cells in stationary power and heat production as well as in automotive applications.

4.2. Overview of the technology

Fuel cells produce electricity and heat from a reaction in which hydrogen combines with oxygen releasing electrons and water. In fuel cells, the reaction is neither explosive nor flammable. As well as pure hydrogen, fuels that can be reformed to release hydrogen are also suitable; these include methanol, natural gas and petrol. A reformer is required to convert these fuels into hydrogen.

Because a fuel cell produces power through a chemical reaction and not via the conversion of thermal power into work, the process is much more efficient than conventional power technologies. Moreover, fuel cells are:

- emission-free when fuelled by pure hydrogen;
- virtually silent;
- modular in construction, allowing power output to be easily scaled up or down;
- able to maintain efficiency under partial load;
- reliable and have low maintenance costs;
- capable of adjusting load rapidly.

Policy-makers need to have a full understanding of the environmental benefits that fuel cells offer relative to currently cheaper incumbent technologies. This insight can then form the basis for deciding whether, and how, to support the realisation of the expected benefits of fuel-cell technology. Looking ahead, the introduction of measures designed to help deliver Kyoto commitments is likely to benefit new technologies such as hydrogen-powered fuel cells. Limits on carbon emissions or carbon taxes would improve the appeal of fuel cells relative to conventional technologies across a range of applications (Treece 1997).

While it is clear that fuel cells offer much to support sustainability, there are also environmental concerns that should not be overlooked. For example:

- the miscibility of methanol means that any pollution incidents could be difficult to contain and manage;
- there may be environmental impacts arising from the production of hydrogen (Pearce 1999);
- the use of other fuels would also have environmental impacts: methanol derived from coal would increase greenhouse effects, while large-scale biomass production as a source of methanol could have an adverse effect on agriculture (Lenssen and Flavin 1996).

The most important fuel-cell technologies and some of their differentiating properties are listed in Table 1.

Table 1: Fuel-cell technologies and their properties

Fuel-cell (FC) type	Operating temperature (°C)	Advantages	Disad-vantages	Intended fields of application
AFC (alkaline FC)	80	Efficiency	CO_2 intolerance	Space and military
PEMFC (polymer electrolyte membrane FC)	80–110	Long lifetime	Water management	Transportation, cogeneration
PAFC (phosphoric acid FC)	200	Mature	Limited lifetime	Cogeneration
MCFC (molten carbonate FC)	650	Internal fuel processing	Short lifetime	Cogeneration
SOFC (solid oxide FC)	1000	Long lifetime	High temperature	Cogeneration

Source: European Commission (1999).

The most environmentally beneficial applications of fuel cells in the future are likely to be in stationary heat and power cogeneration plants and automotive vehicles; fuel cells could also be used in portable devices such as computers or cell phones. Each of these applications has particular characteristics that can be used to determine the most appropriate fuel-cell technology as summarised in Table 2.

Table 2: Fuel-cell capacities and applications

Capacity to generate electricity (kW)	Application	Technology
Micro (< 1 kW)	Portable, personal devices	PAFC, SPFC ([1])
Small (1–5 kW)	Residential, uninterruptible power supply (UPS), remote areas	PAFC, SPFC, SOFC
Medium (5–300 kW)	Industrial, automotive, UPS, cogeneration	PAFC, MCFC, SOFC, PEMFC
Large (100 kW–50 MW)	Buses, ships, cogeneration	MCFC, SOFC (possibly combined with a gas turbine)

([1]) Solid polymer fuel cells.

Source: European Commission (1998).

Some observers feel that fuel cells stand out as a leading candidate technology for achieving large efficiency gains in power systems. Even so, it is conventional energy technologies which obtain the bulk of public subsidies. Annual worldwide public subsidies to conventional energy sources have been estimated to amount to more than USD 300 billion (Johansson et al. 1996).

4.3. Stationary applications: cost considerations

Cost is the main barrier to the widespread uptake of fuel cells in stationary applications. It has been suggested that in stationary electricity production fuel cells would become competitive if costs were reduced by a factor of between 10 and 20, while in transport applications the comparable factor would have to be about 50 (Lequeux 1999).

Several developments have recently enhanced the prospects for fuel cells in stationary applications, particularly in combined heat and power production. As described in the previous chapter of this report, one quarter of the European electricity market was opened to competition in 1999. Many commentators anticipate that in the conditions of liberalised market competition power supply will become increasingly distributed or embedded. Electricity will be produced close to the point of use (Dufour 1998). Transmission and distribution costs, which can amount to around one third of the cost to the user, can be avoided. The location of production systems within urban areas requires low emission levels, which fuel cells can deliver.

A new group of companies, 'independent power producers' (IPPs), has already emerged in the European electricity industry. These companies have demonstrated the capacity to build small, innovative and low-cost power plants (Flavin and Lenssen 1994). The boundaries between energy producers and consumers have become somewhat blurred and there is evidence of increasing convergence between the oil, gas and electricity industries (Zink 1999).

Stationary fuel cells also show promise in developing countries (Singh 1999). There are several reasons for this. Developing economies are growing rapidly and there is an associated rapid growth in demand for power. Moreover, economically active regions can be found that have no access to the national grid. Electricity supply over existing grids is often unreliable, and businesses and wealthy households often rely on back-up diesel generators. According to some studies in South America, hydrogen-related technologies could be competitive under certain circumstances (Marschoff 1998). Furthermore, analysis of the costs of supplying power to bases in Antarctica shows that the savings in operation and maintenance could justify the initial installation costs.

The power output required from stationary applications ranges from 5 to 10 kW for houses, through around 1000 kW for offices, hospitals and industrial plants, to up to 2 MW for local communities.

Due to the existing infrastructure and consequent ease of distribution, natural gas is the current fuel of choice for stationary applications (Sjunnesson 1998). Over the longer term, there is the possibility of deriving natural gas from coal or biomass, and of using hydrogen directly. Some observers anticipate a world where hydrogen could be produced using rooftop solar cells, and then stored until needed (Lenssen and Flavin 1996).

Table 3 presents estimates of required pricing levels for commercialisation. Note that the price levels represent total installed system costs, including operation and maintenance costs.

Table 3: Commercially viable price levels for different stationary fuel-cell applications

Application	Power output	Load factor (%)	Price (1997 USD/kW)
Commercial cogeneration and self-generation	200 kW–2 MW	35–45	1300–2000
Light industrial cogeneration and distributed power	100 kW–20 MW	45–75	1000–2000
Heavy industrial cogeneration, re-powering and centralised stations	High	—	Lower range (reflecting low market values with wide market potential)

Source: Dufour (1998).

These 'targets' may be compared with current prices. The commercial market is currently dominated by the US company, IFC/ONSI, which manufactures PAFC plants having a capacity of 200 kW. They cost USD 3000/kW and can operate on natural gas, methane, propane or hydrogen. The capital costs of the Ballard/Alstom unit have been estimated to be USD 8000/kW (Kendall 1999). The residential power plant to be launched in 2001 by Plug Power is expected to be priced at USD 7000 to 8000/kW (Varley 1999). Siemens/Westinghouse are predicting that the cost of their unfinished Surecell plant would be only USD 1500/kW.

Clearly, there remains much to be done to close the gap between current and target costs. However, research into lower cost production processes and components, together with economies of scale, will help to bring down costs over the medium term. For most technologies, pre-commercialisation is expected to extend for several years into the new millennium, with mass production starting around 2008–10.

The future of fuel cells will depend as much on developments in related technologies as on the evolution of fuel cells themselves. Thus, in the years ahead, fuel cells for domestic applications (currently at the demonstration phase of commercial evolution) may face competition from micro-turbines, which share a number of advantageous features (Hart and Bauen 1998). Micro-turbines are small, high-speed generator plants which combine a turbine, compressor and generator on a single shaft, and have only one moving part. They have the flexibility to operate on natural gas, diesel and petrol, and research is in progress to enable utilisation of low-energy biogases.

As with any new technology, successful mass production of fuel cells is critical to the achievement of the necessary cost reductions. While many observers are optimistic that substantial savings can be achieved through technology refinements and increased production volumes, the question of when cost competitiveness with existing technologies will be achieved remains open to debate.

4.4. Automotive applications: fuels to bet on

For fuel cells in transport applications, hydrogen would have a number of advantages over other fuels, and is considered by many to be the ultimate aim (Ogden et al. 1999). In the short to medium term, however, its distribution and storage involve significant obstacles. This has led to investigation of alternatives such as methanol. Methanol can be stored in a more compact form, and existing refuelling stations could be easily modified for its distribution (Panik 1998). But methanol and other non-hydrogen fuels need reformers to convert the fuel into pure hydrogen. In addition, methanol cannot be considered as an entirely clean fuel as CO_2 is produced in the conversion process.

Ogden et al. (1999) carried out a comparison of hydrogen, methanol and petrol as fuels for fuel-cell-powered vehicles. One element of the work focused specifically on the vehicles themselves, excluding fuel and infrastructure costs, but including costs of drive train and on-board fuel storage and processing. The results are summarised in Table 4.

Table 4: Estimating capabilities and capital costs of fuel-cell-powered vehicles that use hydrogen, methanol or petrol as fuel

Fuel type	Vehicle weight (kg)	Fuel economy (km/l)	Range (km)	Cost per vehicle (USD)
Hydrogen	1170	38	685	3600–6850
Methanol	1287	25	740	4100–7450
Petrol	1395	25	1510	4450–8040

Source: Ogden et al. (1999).

These findings show that, for the same performance, hydrogen fuel-cell vehicles are likely to be simpler in design, cheaper, lighter and more energy efficient than fuel-cell vehicles powered by methanol or petrol. They would, moreover, be pollution free.

Then there is the question of the refuelling infrastructure. In comparing refuelling technologies, both capital costs and fuel delivery costs need to be taken into account. For hydrogen fuel-cell vehicles, one option being explored is to use distributed, stationary natural gas reformers. Hydrogen would be produced from natural gas at the refuelling station and then transferred to vehicles designed to operate with hydrogen fuel. Other options include the following:

- hydrogen produced from natural gas in a centralised steam reforming plant, with distribution by road;
- hydrogen produced from natural gas in a centralised steam reforming plant, with distribution by pipeline;
- hydrogen derived from industrial sources, with delivery by pipeline;
- hydrogen production at the refuelling station though small-scale water electrolysis.

Analysis of these options (based on a specific set of assumptions) reveals that delivery costs would be lowest for on-site production of hydrogen via steam reformer and greatest for on-site-production through electrolysis.

An estimate of the total capital costs of introducing a small-scale refuelling infrastructure was derived by assuming that over the short term it would be possible to use existing hydrogen production capacity. The total capital costs would be higher over the long term, since new hydrogen production capacity would be required. The resulting cost estimates are shown in Table 5.

Table 5: Capital costs of hydrogen infrastructure in the short and long term

Hydrogen supply option	Short-term cost (USD/car) ([1])	Long-term cost (USD/car) ([2])
Hydrogen delivery by lorry from an existing centralised facility versus new steam reformer (in the long term)	80	310
Pipeline delivery from nearby source versus new centralised plant (in the long term)	520	570
On-site production from advanced steam reforming of natural gas	370	370
On-site production from electrolysis	620	620

([1]) Infrastructure capable of supplying a fleet of 18 400 cars (chosen to reflect what could be supported by two dedicated refuelling stations).
([2]) Infrastructure capable of supplying a fleet of 1.41 million cars (chosen to represent 18 % of the full car fleet in Los Angeles in 2010 — equivalent to 153 refuelling stations).
Source: Ogden et al. (1999).

The overall result arising from the comparison (encompassing both fuel infrastructure and vehicles) was that methanol and petrol-powered fuel-cell cars are likely to cost significantly more than comparable hydrogen-powered vehicles. The differentials are of the order of USD 500 to 600/car for methanol and USD 850 to 1200/car for petrol. In conclusion, three long-term fuel strategies were identified.

- Petrol-powered fuel-cell car evolves to hydrogen-powered car: low-cost infrastructure allows a large-scale introduction which, in turn, leads to reduction in costs of fuel-cell technology, which then makes hydrogen vehicles more economically attractive.
- Centrally fuelled hydrogen fleets evolve to mass-market hydrogen-powered cars: could involve the lowest capital cost outlay; the achievement of critical mass in hydrogen infrastructure has a significant impact on costs; evolution is driven by energy or environmental priorities.
- Centrally fuelled methanol-powered fleets evolve to mass-market methanol-powered fuel-cell cars, possibly followed by hydrogen-powered cars: infrastructure cost evolves from being cheaper than for hydrogen to being more

expensive as new capacity is needed; again, achievement of critical mass is important in reducing costs; reduced vehicles costs could stimulate development of hydrogen infrastructure.

While hydrogen may be the lowest-cost option in the long run, at present DaimlerChrysler and other car manufacturers seem to be focusing their efforts on methanol, and most of them have adopted the engine developed by Ballard Power Systems.

The dilemmas raised by the fuel question have led to a number of significant industrial alliances among automotive players and, increasingly, other stakeholders, such as oil companies. In September 1999, DaimlerChrysler and Ford had talks with Texaco, BP and Exxon about developing an infrastructure for fuel supply to fuel-cell-powered vehicles. One of the largest consortia is the California Fuel Cell Partnership, which was launched in May 1999. The partnership plans to deliver around 45 fuel-cell-powered cars and buses to California's roads by 2003. The aim is to test the technology, the readiness of the market and the infrastructure. The partnership involves Ford, DaimlerChrysler, Shell and Texaco.

The future of fuel cells is of great interest to the oil industry. BP Amoco has suggested that this is of greater concern to refiners than ever-tightening emission limits. Uncertainties are compounded by the fact that, as well as fuel cells, the automotive industry is also exploring other novel technologies, such as gas and electric power.

Hydrogen may be an earlier viable alternative for bus fleets than for passenger cars. This is partly because it is easier to accommodate large hydrogen fuel tanks in buses than in cars, and partly because it is easier to build central fuel delivery infrastructures at bus depots than at ordinary fuelling stations. The world's largest fuel-cell vehicle demonstration project, started in March 1998 in Chicago, involves six transit buses. (Gilchrist 1998). The hydrogen-powered buses have a range of 400 km.

4.5. European research targets

European policy on fuel cells is influenced by two main considerations:

- the need to reduce the costs of fuel-cell technology to competitive levels;
- environmental concerns and, in particular, Kyoto commitments.

Because of its potential, fuel-cell technology was given significant EU financial support throughout the 1990s. The total budget allocated to fuel-cell development across the EU in 1995–98 amounted to approximately EUR 80 million. This was estimated to be around half the amount spent on fuel cells in either the United States or Japan (Lequeux 1999).

In the fifth European framework programme (1999–2002), fuel-cell research and demonstration activities are being supported through two programmes: 'Energy, environment and sustainable development' and 'Competitive and sustainable growth'.

Paving the way for rapid commercialisation of affordable and competitive European fuel-cell technologies is a priority. The key targets concern the capital cost of generating capacity and durability:

> 'For the short-term targets are less than EUR 9000/kW and more than 10 000 hours' durability for stationary applications (MW size and a long life), EUR 1000/kW and 1000 hours respectively for mobile (kW size and a shorter required lifetime) applications. For the longer term, the corresponding targets are EUR 1000/kW and > 40 000 hours for stationary applications, and EUR 100/kW and 10 000 hours for mobile applications.' (Lequeux 1999.)

The strategy for achieving these goals was published in 1998 (European Commission 1998). This document outlined recommended orientations for activity to the year 2005. The key priorities of the strategy are summarised in Table 6.

Table 6: European research and development, and demonstration priorities in fuel-cell technology to 2005

Technology area	Research and development	Demonstration
Low-temperature fuel cells (PAFC, SPFC and DMFC ([1]))	• Advanced SPFC and DMFC systems to increase efficiency and reduce cost • Design and development of DMFC operating at 60–130 °C • Design and development of fuel-cell-driven vehicles, especially buses • Advanced energy storage based on SPFC • Cost-effective manufacturing methods for SPFC and DMFC of up to 300 kW	• Demonstration of applications up to 300 kW to study the potential of the technology • Demonstration of PAFC to acquaint end-users with the technology • Demonstration of advanced energy storage
High-temperature fuel cells (MCFC/SOFC)	• Development of modular low-cost internal reforming systems or alternatives • Resolution of the problem of nickel dissolution in pressurised MCFC • Design and development of cost-effective intermediate temperature SOFC • Cheap and effective production methods for simple MCFC and SOFC stacks • Combination of SOFC/MCFC with a gas turbine • Advanced energy storage systems based on SOFC • Advanced concepts of balance of plant	• Demonstration of the reliability and maintenance of MCFC and SOFC plants for both small/medium-scale cogeneration or stand-alone power systems • Demonstration of the reliability of SOFC for transport applications
Fuel processors	• Cost-effective and compact fuel processors capable of processing a large range of fuels • Fuel flexible reformers based on partial oxidation • Cheap and efficient gas clean-up systems	• Demonstration of promising SPFC-based applications for either transport or stationary uses

([1]) DMFC — direct methanol fuel cell.
Source: European Commission (1998).

It can be seen that these activities support broad efforts to achieve fifth framework programme targets and seek to overcome more focused concerns, such as nickel dissolution. Progress in these areas will require a consolidated European approach to encourage exchange of information and experience. Benefits can be gained from synergies between different types of fuel-cell application, so that useful lessons from one area can be transferred to another.

4.6. Conclusion

Recently, there has been a considerable growth in interest in fuel-cell technology among both business communities and policy-makers. Activity aimed at accelerating commercialisation is taking place across the automotive, stationary power and, albeit to a lesser degree, portable application areas. At this stage, the final outcome remains unclear, and there are many uncertainties that need to be resolved. A good example is the automotive sector, where there will be trade-offs between fuel choice, system cost and complexity, and supply infrastructures.

Trends that are shaping the future include the following:

- the emergence of methanol as the short-term fuel of choice for fuel-cell-powered cars;
- reductions in cost, as new processes and components are developed and volume production is started;
- eventual miniaturisation of fuel cells, which can increase their application potential.

As the influence of fuel cells on energy supply increases, and markets adjust, it is easy to envisage the possibility of increasing convergence between various types of applications. For instance, if stationary fuel cells are used to produce power at home, excess electricity may be used to charge electric or hybrid vehicles.

Until recently, attention has been largely focused on the fuel-cell technology itself, and less consideration has been given to its use. As applications evolve closer towards commercialisation, it will soon be time to address ‘market pull’ aspects. As with other new technologies, consumer acceptance will be critical to long-term success. Demonstration projects and other initiatives which help users to gain experience of and understand the technology will have an increasingly important role.

One problem for Europe in commercialisation is that it has been lagging behind the United States and Japan in fuel-cell technology development. However, European companies have already demonstrated that they can exploit the potential of fuel-cell technology not only by relying on indigenous European technologies, but also by building mutually advantageous collaboration arrangements with technological leaders from elsewhere in the world.

The main recommendations that arise from our review are the following:

- developing incentives to encourage new technologies (including fuel cells) for stationary power, while taking into account their environmental performance;
- supporting research and demonstration projects which will speed the path to commercialisation;
- identifying niche locations and applications where demonstration projects can be easily implemented and deliver high value;
- ensuring that best policy practices and technical achievements across Europe and beyond can be identified and built upon;
- considering elimination of permanent subsidies for carbon-intensive fossil fuels.

To conclude, although the significant deployment of fuel cells may not take place for another decade or so, the near-term actions of stakeholders, including policy-makers, will have a crucial influence on Europe's future role and competitive position in fuel-cell technology.

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5. Nanotechnology: the need for interdisciplinary cooperation

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Summary

Scientists and engineers are approaching nanotechnology from three directions: microelectronics, biotechnology and chemistry. In electronics, nanotechnology is seen as a necessity in order to maintain the momentum of miniaturisation. Chemistry offers means for producing some of the molecular components that are going to be required in nanotechnological devices of the future. Sophisticated molecular structures discovered in biotechnology offer some models of mechanical and electrical achievement. What is needed now is to enhance the cooperation between the constituent fields of nanotechnology.

5.1. Introduction

In microelectronics, energy technology and biomedicine, some of the most crucial technological needs of today are related to nanotechnology. We would like to have more compact high-capacity lightweight batteries, more efficient solar energy technologies, less expensive high-resolution flat panel displays and more efficient means to transport drug molecules to targeted cells. Solutions to these problems are likely to be based on methods that border on nanotechnology.

In 1999, numerous findings and policy decisions concerning the budding field of nanotechnology were reported.

- The US company Agilent Technologies fabricated logic gates from an array of configurable molecular switches. The achievement illustrates the potential of new fabrication methods which can lead us from microelectronics to nanotechnological devices.
- The Dutch multinational, Philips, announced that it had developed a prototype of a small monochrome display based on organic light-emitting diodes (OLEDs). The technology is expected to be used in large, bright flat displays of the future.
- Research groups in the United States and the United Kingdom developed prototypes of photonic crystals, the basic building blocks of photonic computers and communication systems of the future.
- Steps to stimulate RTD in nanotechnology were taken in many countries, including the United States and Germany. Research programmes on nanotechnology were planned, announced or launched in several countries.

Early prototypes of nanotechnological components are already emerging in research laboratories where methods for working on nanometre (10^{-9} m) scale are being developed. The new methods will provide new means for fabricating components from thin layers of atoms and for manipulating individual atoms or groups of them. Nanoscience has raised tremendous interest ever since new tools made the characterisation, preparation and manipulation of small structures practical in research. The challenge is to develop technologies that would also be practical and economical in industry. In response to this long-term challenge, many countries have launched programmes to take advantage of technological opportunities in nanotechnology.

5.2. The driving forces of nanotechnology

The origins of nanotechnology go back to a talk given by Richard Feynman in 1959. In his talk, Feynman discussed the possibility of making wires of 10 or 100 atoms in diameter and building components for computers by evaporating materials layer by layer. ‘In the year 2000, when they look back at this age, they will wonder why it was

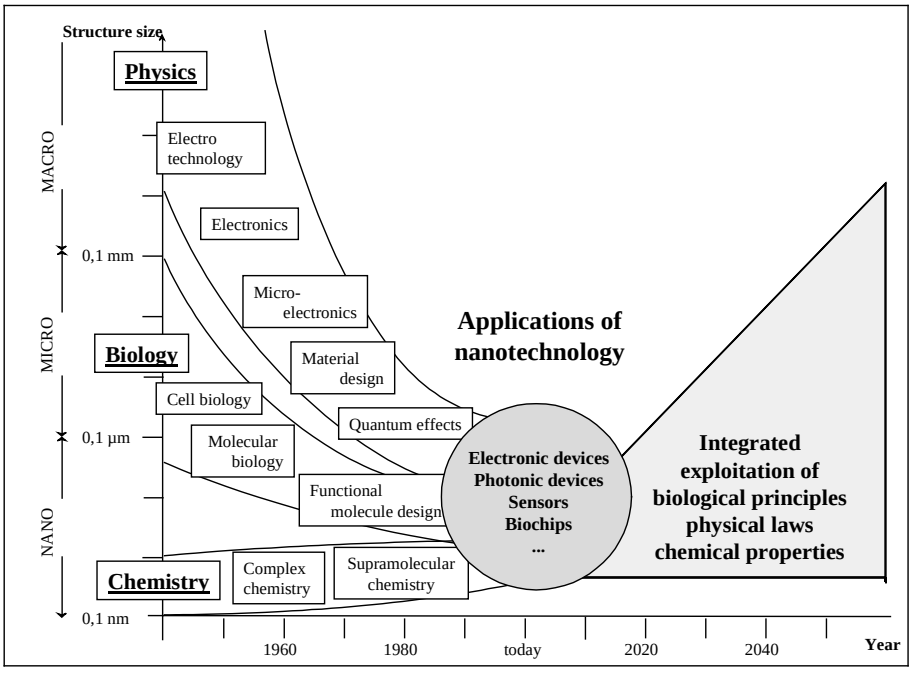
not until the year 1960 that anybody began seriously to move in this direction,' he said. (Feynman 1960.)

One of the first practical applications of Feynman's ideas was the scanning tunnelling microscope invented in the IBM research laboratory in Switzerland. In 1986, Gerd Binnig and Heinrich Rohrer received the Nobel Prize for their invention. The scanning tunnelling microscope and related technologies have made it possible to view and control individual atoms, and have started a rapid phase in the development of nanotechnology.

Researchers and technologists are approaching the field of nanotechnology from three directions.

- Microelectronics continues to race towards smaller feature sizes and has already advanced to submicrometre line widths. In the near future, the processors in our computers will have line widths of 180 nm — and they too will soon be obsolete.
- In chemistry, improved knowledge of complex chemical systems has led to the realisation of new catalyst, membrane, sensor and coating technologies. These technologies rely on the ability to determine and shape minute details of material structures.
- Living systems have functional subunits with sizes between the micrometre and nanometre scales. Combining the functional parts of such molecular structures with man-made technical systems can lead to new medical, pharmaceutical and diagnostic products.

Figure 1: Physics, biology and chemistry meet in nanotechnology



Source: VDI-Technology Centre, Future Technologies Division.

It is possible that as nanotechnology gains in maturity it will become more difficult to distinguish what the contributions from physics, biology and chemistry are in nanotechnology. Instead, a nanotechnological research and production paradigm may emerge. It will be based on the laws of physics, chemical properties of materials, and a few principles adopted from biological systems. The process is shown schematically in Figure 1, where nanotechnology is seen to emerge from the integration of its main driving forces — physics, biology and chemistry.

5.3. Nanotechnology and electronics

The field of industry that is awaiting the onset of the age of nanotechnology with the most urgent interest is electronics. The emerging information society is increasing the demand for mobile, efficient and robust information-processing devices that would have fast transfer rates and processing speeds, high storage densities and brilliant display units. The familiar metal-oxide semiconductor (CMOS) technology will be able to support the required advances for at least a decade, but eventually the miniaturisation needs are going to surpass the limits of the CMOS technology. In 1999, international experts preparing a roadmap for semiconductor technology acknowledged that optimistic projections are required to support the belief that current technologies can continue to be used to support miniaturisation for the next 15 years (ITRS 1999). One sign of trouble on the horizon is the increasing cost of process equipment and factories. The cost of building new microelectronics factories is rising at a rate exceeding that at which electronics markets are growing.

Eventually, much less expensive manufacturing processes will have to be invented, and even non-conventional methods will have to be tried. Radical new solutions could emerge from molecular electronics. Molecules that have been so designed that they have the necessary electronic and self-assembly properties could be synthesised relatively cheaply in chemical batch processes. When brought together, these molecules would assemble by themselves into electronic circuits in a process that resembles a chemical reaction. The result would be components that have far higher capacities than today’s memory systems and much better power efficiencies than current CMOS circuits.

The problem is that self-assembled molecular circuits would contain large numbers of broken connections and component defects. In 1998, a massively parallel computer was built in a process that left more than 200 000 hardware defects in it of the kind that would stop any conventional computer. Yet the computer operated well and was a hundred times faster in some tasks than an ordinary computer. Powerful algorithms were used to locate defective components, which were then programmatically excluded from operations. (Heath et al. 1998.) In 1999, the work was continued by demonstrating that switches required in a defect-tolerant computer can be fabricated in molecular dimensions. It was shown that AND and OR logic gates can be configured from such molecular switches. (Collier et al. 1999.)

Ultimately, it may become possible to develop electronic systems that take advantage of quantum phenomena in information processing. One possibility for development of

a quantum computer system that would be compatible with existing semiconductor technology is to exploit not only the charges of electrons, as present electronic devices do, but their spins as well. The spins of electrons point to a common direction when the material is magnetised. Magnetic information storage is a USD 50 billion industry, and increasingly efficient technologies are coming onto the market. The first results of injecting a spin-polarised current into a non-magnetic semiconductor were reported in 1999 (Fiederling et al. 1999). The future could bring spin transistors, spin memory systems or even spin quantum computer systems.

The electrical resistance of certain materials can be changed by exposing them to a magnetic field. This magnetoresistive effect is already being applied in read heads of computer hard disks, and, as a result, the capacity of these disks has been raised to more than 20 Gbits, and the United States has a strong lead in hard-disk production. In the future, it could become possible to apply the technology in the production of non-volatile magnetic random access memory (MRAM) chips. Computers equipped with such chips could be switched on and off instantly, without the booting process to which we are so accustomed. Eventually, chips with 10 Gbit memories could emerge, rivalling the storage capacities of hard disks common today, but much faster.

In the future, it may also be possible to build terabit memory devices from single-electron components (Matsumoto et al. 2000). In 1999, NEC researchers in Japan created the first electrically controlled bit of quantum data, or qubit. They made pairs of electrons oscillate back and forth between two superconducting components, thus representing the one and zero of a digital system. It will be a long and difficult challenge to prevent qubits from decaying instantly. Eventually, however, such findings could be applied in a quantum computer (Service 1999a). In the distant future, it may become possible to develop not only single-electron devices, but also single-photon devices (Kim et al. 1999).

Carbon nanotubes have potential in many fields. Their width is perfect for nanotechnology — only about 1 nm. In electronics, carbon nanotubes have potential as tiny conducting wires that could help to reduce the dimensions of electronic circuits. In field emission displays, nanotubes could serve as efficient electron emitters. The first display prototypes are under investigation. In energy technology, carbon nanotubes may be used in the future to store hydrogen. The German research ministry began a project in 1999 that will investigate the hydrogen storage capacity of several carbonaceous materials (BMBF 2000).

Another promising technology for flat panel displays is light-emitting organic polymers. Organic light-emitting diodes (OLEDs) are already the basis of a new type of flat panel display, in which suitable polymers have been arranged between two glass plates, which serve as electrodes. Putting voltage on the electrodes causes the polymers to emit light. The displays are light and flexible and therefore suitable for smart cards, global positioning system (GPS) navigation systems, palmtop computers, and cell phones. In 1999, the first display based on organic polymers came onto the market. The display, built by Pioneer, is used in a GPS system. Later, Philips introduced a small monochrome OLED display. OLEDs could enable European companies to gain a foothold in the display market.

5.4. Nanotechnology and photonics

One of the most important aims of nanotechnology is to build photonic devices in which photons or quanta of light are controlled in ways that are analogous to the behaviour of electrons in semiconductor materials. Semiconducting materials prevent the propagation of electrons at certain energy levels. Photonic materials have a corresponding property regarding photons. Semiconductors are built by stacking layers of atoms. Photonic materials are being designed similarly as arrangements of dielectric materials known as photonic crystals. These components suppress the propagation of light in a certain frequency range, but allow other frequencies to pass, and even make waves of light bend, around sharp corners.

Only recently has it become possible to fabricate the micrometre-size components required in the manipulation of visible light waves. In 1999, research teams built photonic crystals and demonstrated how tiny lasers can be built with them (Levi 1999). It was also shown that it is possible to tune the properties of photonic crystals with the help of a liquid crystal material (Busch and Sajeev 1999).

The development of practical applications for photonic crystals is made difficult by phenomena related to the interference of light waves. At present, researchers are trying to improve the methods of fabricating photonic crystals. One method is based on deposition of atoms, layer by layer, and others include self-assembly methods in which particles suspended in a liquid arrange themselves into desired structures. The main focus of research is on the search for suitable materials.

The hope is that in future it will become possible to apply photonic crystals in increasingly practical miniaturised lasers, switches, waveguides and interconnections. Mass-produced integrated circuits consisting of such components would be much smaller and faster than those based on flows of electrons. Consequently, future applications of photonic crystals could revolutionise the capabilities of high-speed communication networks and computer technologies. A single optical fibre could carry as many as 100 million phone calls. The impact on workstations, palmtop computers and mobile phones could also be considerable.

5.5. Nanotechnology and biotechnology

Almost all chemical reactions sustaining life are based on small nanotechnical engines known as enzymes. To fulfil their function, some enzymes are known to distort their target molecules. An enzyme typically increases the rate of reaction by a factor of between 10^6 and 10^{24} (Benkovic and Ballesteros 1997: 385).

One of the most important enzymes in nature is ATP synthase which produces energy-carrying ATP (adenosine triphosphate) molecules in specialised cell organelles known as mitochondria. The structure of ATP synthase resembles a motor; its shaft is rotated by the motive force of protons in the mitochondrion. The mechanical energy of the shaft movement is essential in ATP production. The motor

can also run in reverse, and then it burns ATP fuel molecules making the shaft spin at near 100 % efficiency. In 1999, scientists genetically engineered ATP synthase motors so that they could be fixed on a metal surface. The rotating end of the motor was modified to attach small man-made beads on them. In a test, just such motors fuelled by ATP rotated the beads for up to two hours. In the distant future, ATP synthase motors could be used to power complex nanometre-scale mechanisms. By rotating tiny magnetic bars, they could even produce electricity to drive molecule-sized devices such as drug-delivery pumps. (Service 1999b.)

The development of drug-delivery systems seems to offer an attractive area for the practice of emerging nanotechnologies. Even relatively simple structures such as biodegradable molecular cages, protecting drug molecules until they reach their targets, could be very useful. At present, it is not possible to use many protein-based drugs, because they do not survive long enough in the body or because cells do not accept large molecules. Many promising drug compounds cannot be used because they are not soluble. In the future, it may become possible to use nanotechnological means to manufacture these compounds in a form in which they can be delivered to targeted organs or cells.

Due to its ability to store huge amounts of information, DNA attracts the interest of genome scientists as well as nanotechnologists. It is possible that in the future pieces of DNA will be used either as components in nanotechnological devices or in the process of fabricating molecular devices. In 1999, a Chino-German research team at the University of Saarland announced a breakthrough in the mechanical manipulation of individual DNA strands (Brettar 2000). It is possible that also in the future DNA strands will be read with the help of scanning probe techniques in the same way as the needle of an old record player reads the topography of an LP record. As described in the chapter on DNA diagnostics in this report, methods used to interpret DNA information are developing rapidly.

5.6. International nanotechnology initiatives

In 1999, research funding given to nanotechnology was roughly at a comparable level in Europe, Japan and the United States. There were signs that interest in nanotechnology was growing.

- In the United States, a major national initiative on nanotechnology is going to be launched during the fiscal year 2001. According to the budget request presented to Congress in January 2000, the national nanotechnology initiative would increase annual federal funding by more than USD 200 million or 80 %. (NSTC 2000: 11.)
- In Germany, six centres of competence in the field of nanotechnology have begun their work. These centres will strengthen networks of research institutes and industry and bring together researchers and venture capitalists to disseminate information and results, coordinate training, and stimulate formation of start-up companies.
- Switzerland launched its TOP NANO 21 programme in 1999. Cross-disciplinary synergies are to be exploited in the effort.

- The second European Conference on Nanotechnology was held in Antwerp in 1999. Advanced nanometre-sized materials were a major topic.

5.7. Conclusion

In 10 to 15 years, nanotechnological solutions are going to be urgently required to keep up the momentum of progress in electronics. Recent results suggest that it may become possible to develop the required methods of molecular electronics in time to respond to that challenge. Molecular mechanisms discovered in biotechnology seem to offer surprisingly sophisticated components for future nanotechnological systems, but we may have to wait a considerable period of time before practical applications can be realised. What is not in doubt is the need to continue investing in research and training in nanotechnology.

Nanotechnology is bringing together physicists, chemists, biologists, and engineers. What is also needed is training to educate nanotechnology specialists with strong interdisciplinary research skills. Close interaction is required, for instance, between biotechnology and nanotechnology. But rather than dividing nanotechnology into 'wet' or 'dry' areas, it would be important to encourage the development of nanobiotechnology as a unified field not only in research, but also in training.

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6. Environmental indicators: the rules of the game

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Summary

Decision-makers and the general public increasingly feel a need for reliable information on the status of the environment. Environmental indicators are designed to reveal such information in a condensed form. But what are the rules of the game — how should environmental indicators be designed and how should their trustworthiness be maintained over years and even decades? And what are the proper uses of environmental indicators in decision-making? The challenge for the European decision-makers is to foster the development of robust, informative indicators and to maintain awareness of the uses and limitations of such indicators.

6.1. Introduction

Each year, the EU Member States publish data on the development of environmental parameters such as SO_2 emissions, biological oxygen demand (BOD) of wastewater emissions, pH levels of soils, and levels of noise in residential districts (EEA 1999c). Information on these parameters is valuable, and when compared with figures from previous years such information can be used to evaluate how the environment in Europe is being affected by human activities. However, by themselves most of such figures are not indicators. They become indicators only if they are chosen to be pointers to politically relevant factors in the environment. In addition to being policy-relevant, indicators are designed to present aggregate information in a condensed and user-friendly form.

Indicators are by definition quantities that have been calculated from sets of data. At present, economic indicators such as the rate of inflation or the level of GDP are much more familiar than environmental indicators. The well-established figure on the economy-wide inflation, for instance, tells us something very important about the condition of the economy. The power of the indicator is based on the accuracy with which data collection has been carried out and also on the appropriateness with which various aggregating calculations have been carried out. However, changes in the methods used in calculating unemployment indicators remind us that the design of indicators can be subject to change, and that care must be taken in comparisons that stretch over long periods of time.

In 1999, several important developments related to environmental indicators took place.

- At the Helsinki Summit, the European Commission published its report on environment and integration (European Commission 1999a). According to the report, 'indicators can supplement regular state-of-the-environment reports to assist in the process of monitoring progress with environment policy and in integrating environmental concerns into different sectoral policies'.
- Eurostat (the Statistical Office of the European Communities) published data for 60 indicators which had been identified as especially relevant by several advisory groups (European Commission 1999b). The two-volume publication provides detailed information on procedures used, data availability and quality, political relevance and perceived problems.
- The Organisation for Economic Cooperation and Development (OECD) published environmental indicators for agriculture. The publication covers the concepts, framework and design of environmental indicators related to this sector. (OECD 1999.)
- The European Environment Agency (EEA) published a report 'Environment in the European Union at the turn of the century' (EEA 1999d). Special emphasis is laid on indicators that link environmental problems with trends and activities in various sectors of the economy. Equally monitored is the progress in the use of economic instruments and environmental management systems.

- The Austrian Ministry of the Environment published time series for a set of indicators that connect sectoral activities with environmental issues (BMUJF 1999). The publication shows that consumption of resources and emissions of air pollutants are growing at a slower rate than the national economy. These initial signs of decoupling between economic growth and consumption of environmental resources do not yet mean that in absolute terms resource consumption is declining — in fact it is growing.
- The Italian environmental organisation, Legambiente, announced the new outcome of its environment quality ranking system for major Italian cities, *Ecosistema Urbano 1999*. The northern cities, particularly in Lombardy, still hold top ranks. Pavia was considered to be the best place to live and was followed by Bergamo and Como. There was a break in the normally observed diminution of the north–south contrast. Several regions were completely absent from the list of top-ranking cities: Puglia, Basilicata, Calabria, Sicily and Sardinia. (Legambiente 1999.)
- The World Business Council for Sustainable Development (WBCSD) published an executive brief on eco-efficiency indicators (WBCSD 1999). Both motivation and methodology are explained, core and supplemental indicators are defined, and communication and test procedures are outlined. The results of a broader test and evaluation programme are expected in 2000.
- Malaysia decided not to disclose readings of its air pollution index as hazy conditions linked to forest fires in Indonesia returned. The Science, Technology and Environment Minister, Law Hieng Ding, was quoted as saying that the Cabinet made the decision so as not to ‘drive away the tourists’. (AFP 1999.)

The examples above show how indicators can be assigned to environmental variables and how they can provide information on the environment. Indicators can be monitored over periods of time, and the resulting time series can be used as evidence in deciding whether there has been improvement or deterioration in the quality of the environment. Our examples tell us more. They show how indicators can influence public opinion. That is why it is possible that attempts are made to manipulate them. The value of an indicator depends on its credibility and that is not achieved without a conscious effort.

So what are environmental indicators? They are designed to describe the current status of the environment and identify various existing pressures. Indicators help to inform the public and facilitate communication about environmental issues. Environmental indicators can be used to predict future trends, and show how society reacts to changes in the environment. These are what are known as the descriptive tasks of indicators. Environmental indicators also help to assess changes in the environment and evaluate its current status. That is why they also have a normative role. They support public decision-making and evaluation of policy measures.

Some environmental indicators can be defined in terms of pure science. One example is the global warming potential, a relative number that expresses the calculated impact on climate that a certain quantity of a greenhouse gas has compared with the same amount of carbon dioxide. Some environmental indicators reflect economic costs or indicate provision of abatement technologies by portraying environmental

expenditure. They can also be seen as a proxy for living conditions as in the case of indicators of the quality of beaches and bathing water.

At the Helsinki Summit, the Heads of State or Government were told that indicators should answer the following questions: ‘Is there a general improvement in the state of the environment? Do key sector policies take environmental concerns into account? Can sustainable development be achieved in sectoral policies and for society as a whole?’ (European Commission 1999a.) The recommendation was that while progress has been made towards the development of an environmental and sectoral indicator system, ‘considerable effort is still required to complete the system’. The Heads of State or Government were asked to accelerate progress on sectoral indicators. (European Commission 1999a.)

Some interesting results of indicator development were published in connection with the Helsinki Summit. Information on two sets of indicators was made available. Environmental headline indicators are designed to present a general picture of trends in key (9 or 10) environmental areas. They can help alert policy-makers to the need for political action and raise public awareness of specific environmental problems. The second group is a broad set of indicators that cover a wide range of environmental topics, comprising 60 to 70 indicators prepared by the EEA. This group is principally targeted at environment decision-makers. (European Commission 1999a.)

Data on environmental headline indicators for the EU show, for instance, that in 1996 greenhouse gas emissions were down by 2 % on 1990. They are projected to increase by 6 % between 1990 and 2010 unless new measures are undertaken. The total amount of energy used in the EU increased by 7 % between 1990 and 1997. Renewable energy sources contribute less than 6 %. Travel by car increased steadily by 2 % per year between 1990 and 1997, whereas bus transport increased by 0.9 % and train transport by 0.4 % per year.

In many cases, environmental indicators describe phenomena that cannot be measured exactly, and indicator data can be interpreted from various standpoints. Moreover, what is also peculiar to environmental indicators is that their definition involves the balancing of several goals. This is because environmental indicators are used to provide information to the general public, to foster communication among interested and concerned groups and stakeholders, to identify measures of environmental policy and to monitor the effects of environmental policies.

6.2. The evolution of indicator systems

The desire to have indicators is not new. Indicators of environmental quality and of effects caused by human activities have been discussed for at least 20 years. A major step for a worldwide commitment to establish such indicators was taken at the United Nations Conference on Environment and Development (UNCED) in June 1992 in Rio de Janeiro. Goals for sustainable development were formulated in Agenda 21, and the need to establish indicators to measure progress was accepted. (BMU 1992.) The UN

Commission on Sustainable Development (CSD) was founded to supervise and enforce the implementation of the agenda, and, in 1996, published a list of 130 indicators for sustainable development. During 1999, the competent organisations in several pilot countries tested the proposed set, evaluated possibilities for practical implementation as well as the availability of required data, and made recommendations for further improvements.

Two approaches for the construction of environmental indicators can be differentiated. On the one hand, in a top-down approach, one starts from a scientific model or societal goal system from which criteria for indicator standards and requirements are then deduced. Existing information is assessed to consider if it meets these requirements. In practice, the indicator-constructing procedure must be sufficiently open, so that new environmental issues may be included (ensuring problem adequacy). On the other hand, in a bottom-up approach, one starts from a comprehensive description of the environmental situation and aggregates information into higher-level indicators. In this process, one should consider carefully which data are necessary for the next aggregation level (ensuring goal adequacy). (SRU 1998.)

General quality criteria for the indicators refer to the transparency of the construction procedure, to reproducibility of results and the intelligibility of selection criteria. The criteria are all the more important in the case of environmental indicators, because they always depend on assessments and values.

6.2.1. Uses and applications of environmental indicators

The main application of environmental indicators is in reports on the state of the environment. Official reports are issued by international bodies, EU institutions, individual countries, provinces, and municipalities. Many companies, too, publish environmental indicators in their annual reports.

In a recent survey, it was found that all EU Member States published, in 1997, environmental indicators following a particular (DPSIR — driving forces, pressures, state, impacts, and responses) framework (EEA 1999a). This finding shows that the publication of descriptive environmental indicators is accepted as an obligation by each Member State. However, so-called ‘efficiency indicators’ (cf. Section 6.3.3), such as the amount of emissions per capita, have not been published as comprehensively. Most of the 60 Eurostat pressure indicators are systematically presented ‘per capita’ or, in the case of land use, ‘per areal unit’. Even less comprehensive information has been published on performance indicators that measure the gap between the current state of the environment and the desired situation or targets. One gap indicator on which information has been published concerns acidification. The related emissions and depositions have been compared to critical loads. The French report, *Environmental performance indicators in France*, offers the best overview of performance indicators (cf. IFEN 1998).

An important use of indicators is their inclusion in systems of warning and alerts. One such indicator concerns the quality of bathing water at European beaches. The

indicator is based on Directive 76/160/EEC, and the data are published by competent authorities of the Member States and can be accessed on the Internet.

Other familiar indicators are related to air quality. Ground-level ozone concentration can be used as an indicator for health risks related to the respiratory system. If threshold values are exceeded, warnings are broadcast by radio and television to the general public. In Germany and some other Member States, competent authorities are entitled to restrict the use of motor cars, if certain parameter values are exceeded (Germany 1996).

The application of indicators for the evaluation of policy programmes is relatively new. In Europe only one such exercise has been carried out. The study reviewed successes and failures of the fifth environmental action programme (EEA 1996).

6.3. International goals and accomplishments

6.3.1. The evolving pressure–state–response (PSR) framework of the OECD

In the development of environmental indicators, many practical results have already been achieved by the OECD. The demand for environmental indicators originated from an OECD Council meeting at ministerial level in 1989. At this meeting, more effective integration of economic and environmental decision-making as a means of contributing to sustainable development was called for. This idea was further enforced at the G7 Economic Summits in Paris (1989) and Houston (1990).

A formal recommendation on environmental indicators was approved by the OECD Council in 1991. The development of ‘sets of reliable, readable, measurable and policy-relevant environmental indicators’ became a new commitment. A set of indicators was published in 1991 to be used as a tool in environmental performance evaluation. A common conceptual framework was developed in 1993 in a series of workshops of the OECD Group on the State of the Environment.

A revised list of indicators and initial detailed numerical data and figures were published in 1994 (OECD 1994). In this publication, a core set of indicators was defined and applied in environmental reviews. General social indicators, such as population growth, industrial production, energy use, trends in road transport and expenditures for pollution control, were also presented. As can be seen from Box 1, the 1994 core set of indicators reflected the main environmental concerns of OECD countries.

In the second OECD indicator report published in 1998, the core set of definitions remained the same thus enabling comparisons with the previous report (OECD 1998). The general indicators’ part was considerably enlarged to meet the new requirements arising from issues of sustainable development. A set of indicators referring to socio-economic trends, sectoral developments, general economic conditions and population growth was added. This inclusion reflects the ongoing discussion about the driving forces behind the generation of pressures on the environment. Sectoral indicators can

provide more insight into how to integrate environmental concerns into sectoral policies.

Box 1: 1994 OECD core set of indicators

Climate change
Ozone layer depletion
Eutrophication
Acidification
Toxic contamination
Urban environmental quality
Biodiversity, landscapes
Waste
Water resources
Forest resources
Fish resources
Soil degradation (desertification and erosion)

The OECD identifies two major functions for indicators. First, they should reduce the number of measures and parameters which normally would be required to give an 'exact' description of a situation. Second, they should simplify the communication process by which the results of measurement are provided to the user. In its indicator development, the OECD uses a pressure–state–response framework, in which 'human activities exert pressures on the environment and change its quality and quantity of natural resources. Society responds to these changes through environmental, general economic and sectoral policies.' (OECD 1994: 8–9.)

Three types of indicators can be differentiated within the OECD framework. Indicators that describe environmental pressures arising from human activity often cover emissions or rates of resource consumption. Indicators of the state of the environment include those that concern pollutants found in the environment, remaining wildlife or stocks of natural resources. Indicators of societal responses reflect human actions that aim at mitigating or preventing environmental problems.

A further extension of the indicator reporting scheme is the integrating of relevant information from environmental accounting systems. From the various existing approaches of accounting, the OECD selected the method of physical input–output tables. The production, transformation and use of each resource are monitored throughout the economy. This information is used to define indicators such as the intensity of forest use or the intensity of use of water resources.

In the two volumes on environmental indicators for agriculture, published in 1999, 13 priority agri-environmental issues were identified. For each issue, several indicators were proposed together with recommendations for indicator construction and use. (OECD 1999.) The publication is part of ongoing work on sustainable development,

and a report is being planned for the OECD Ministerial Council meeting in 2001; the report would be an input into the Rio + 10 Conference in 2002.

6.3.2. The driving forces of the Eurostat approach

The results of the United Nations Conference on Environment and Development prompted the former Commission President, Jaques Delors, to convene a group of European Commission officials to discuss options for providing statistical tools to environmental policy-makers. The general idea was to create an information system that would become as convincing and reputable as the system of national accounts.

The solution of using the 'green' GDP concept was rejected in favour of a two-step approach. First, to complement the national accounts, satellite accounts for environmental issues were to be established. Second, physical indicators and indices related to pressures of human activities on the environment were to be prepared. The Commission decided to support this approach and charged Eurostat with the realisation of the task. (European Commission 1994.)

Eurostat modified the OECD PSR approach into a model comprising driving forces, pressures, state, impacts, and responses (DPSIR). The new driving force concept is used in monitoring sectoral trends such as production volumes or energy consumption in different sectors of the economy. The approach is based on the insight that anthropogenic effects on the environment most often arise from continuous human activities such as energy production or the use of transport systems. Driving forces can be used to create models and scenarios in which simple coefficients such as CO_2 emissions per car-kilometre can be applied. Simple scenarios can help to evaluate actions needed to prevent future problems, such as the loss of arable land under roads or housing.

For Eurostat, environmental indicators are tools in the process of political decision-making. They make it easier for decision-makers to communicate amongst themselves and with the concerned public. Accordingly, indicators have to address relevant problems and political issues. They need to be accepted, which, in turn, implies that certain quality criteria have to be fulfilled. In contrast to the usual approach of asking politicians and other decision-makers what kinds of indicators they wanted, Eurostat entrusted this problem to the scientific and environmental community.

The establishment of pressure indicators was the first task. The list of policy themes of the European Commission's fifth environmental action plan was taken as a guideline. From this list, 10 separate policy fields were identified and are given in Box 2. But this did not yet provide a straightforward procedure for the establishment of indicators.

Box 2: Eurostat policy fields

Climate change
Ozone layer depletion
Loss of biodiversity
Resource depletion
Dispersion of toxic substances
Waste
Air pollution
Marine environment and coastal zone
Water pollution and water resources
Urban environmental problems

Eurostat chose a two-step process. A total of 2400 experts were consulted and they prepared some 1000 proposals. From these proposals, a list of 30 indicators for each of the 10 policy fields was selected. In the second round, the advisory groups were asked to rank the indicators for each policy field according to the criteria of policy relevance, analytical soundness and responsiveness. The six highest-ranking indicators became the final set which is used to cover each policy field. As an example, indicators for loss of biodiversity are presented in Box 3.

Box 3: Eurostat indicators for loss of biodiversity

LB-1: Protected area loss, damage and fragmentation
LB-2: Wetland loss through drainage
LB-3: Agriculture intensity: area used for intensive arable agriculture
LB-4: Fragmentation of forest landscapes by road/intersections
LB-5: Clearance of natural and semi-natural forested areas
LB-6: Change in traditional land-use practice

The first publication with concrete figures for the 60 indicators was issued by Eurostat in 1999 (European Commission 1999b). Indicators — together with time series, when possible — were presented for each of the 15 EU Member States.

The Eurostat publication shows, among other things, that emissions of nitrogen oxides (NO_x) in 1996 were down by only 8 % on 1980. That leaves much ground to be covered if the 30 % reduction target for the year 2000 is to be reached. The target was set in the large combustion plant directive (Directive 88/609/EEC). Another finding is that annual municipal waste generation remains at a high level of more than 500 kg per capita in Denmark, Germany, France, the Netherlands and Austria. Greece, Spain, Ireland, Portugal and Sweden generate less than 400 kg per capita. In Belgium,

Luxembourg, Italy and Finland, the corresponding figure is between 400 and 500 kg per capita. In many countries, decreases in amounts of waste have occurred during the past few years, but Spain and Portugal show considerable increases. The use of pesticides in agriculture has also decreased during the past few years. This has occurred partly as a result of the changes in the common agricultural policy (CAP) since 1992 and partly as a result of new products that require lesser amounts. Policies in Denmark, the Netherlands and Sweden aiming to reduce pesticide use have also had an impact.

The lack of comprehensive and timely data for the construction of sector-specific indicators has prompted Eurostat to develop another system of environmental indicators, the environmental pressure information system (EPIS). The aim is to use existing statistics from various sectors of the economy to develop tools for presenting and modelling data on environmental pressures arising from activities in these sectors. This process is facilitated by the fact that statistics based on a common nomenclature system (Prodcom) are available for the last few years. By using simple models that provide links between economic activities and environmental impacts, comparable data for all Member States will be produced.

For the time being, some 100 to 150 high-pressure processes have been identified. In the future, Eurostat and the EEA will follow a division of labour in publishing new data. Eurostat will concentrate on driving forces, pressures and responses, while the EEA will produce state and impact indicators. Both will substantially rely on the same data sources.

The possibility of developing a unified aggregate index on European environmental pressures continues to receive attention. While there are well-established indicators such as gross domestic product for economic activities, similar aggregate indicators are not yet available for environmental pressures. In the distant future, it may become possible to devise a single index of sustainable development that would combine economic and environmental information. (Jesinghaus 1999.)

6.3.3. European Environment Agency indicators

The European Environment Agency, established in 1990, intends ‘to provide the Community and the Member States with objective, reliable and comparable information at European level enabling them to take the requisite measures to protect the environment, to assess the results of such measures and ensure that the public is properly informed about the state of the environment’ (Jiminez-Beltran 1995). The first attempt to initiate the use of environmental indicators was the so-called ‘Dobríš report’ (EEA 1995). This report was the result of the conference of environment ministers of all European countries at Dobríš castle in the Czech Republic in 1991 where a new political process, ‘Environment for Europe’, was launched. The aim of this initiative is to inspire, define and coordinate environmental policies throughout Europe.

The chapter topics of a follow-up report are listed in Box 4 (EEA 1998). The publication provides detailed problem descriptions, as well as information on driving

forces, temporal developments of selected pressure parameters, and policy measures and their outcomes. Explicit indicators were not produced, although some of the quoted parameters resembled indicator definitions of the OECD and Eurostat.

Box 4: Chapter topics in *Europe's environment: The second assessment*

Climate change
Stratospheric ozone depletion
Acidification
Tropospheric ozone
Chemicals
Waste
Biodiversity
Inland waters
Marine and coastal environment
Soil degradation
The urban environment
Economic developments
Technological and natural hazards
Integrating environmental politics

The EEA fully adopted the DPSIR framework. Special emphasis was laid on the links between DPSIR elements. The EEA classifies indicators into four groups.

- Descriptive indicators provide an answer to the question: What is happening to the environment and to humans?
- Performance indicators compare (f)actual conditions with a specific set of reference conditions. They measure the distance between the current situation and the desired situation (targets).
- Efficiency indicators relate separate elements of a causal chain. These indicators provide insight into the efficiency of products and processes, sometimes in the efficiency of political measures.
- Total welfare indicators measure the total sustainability, like a green GDP. (EEA 1999a.)

With these enlargements to the original DPSIR model, the EEA takes part in the ongoing discussion on how to measure progress in developments towards sustainability and how to link developments in single sectors to environmental problems and issues.

An explicit indicator-based publication has not yet been published by the EEA, but it has been announced to be forthcoming in 2000 and will be entitled *European environmental signals 1999 — EEA regular indicator report* (EEA 1999b).

6.4. Conclusion

For interest groups, administrative bodies and the general public, environmental indicators can be a reasonable tool for communication on environmental problems and issues. The definition and construction of relevant indicators have reached a level of maturity in some fields such as air pollution. In others, considerable work remains to be done.

In the near future, indicator development can be expected in various directions.

- Integration of environmental and sectoral information: considerable results have been achieved in the transport sector (EEA 1999e) and agriculture (OECD 1999).
- Environment and sustainable development: in the list of indicators of the UN Commission on Sustainable Development, there are 54 indicators related to environmental issues. In 1998 and 1999, several countries tested the indicator methodology. (UN 1999.)
- Indicator developments in the private sector: many companies already publish company-related indicators in their environment reports. A general framework for this type of indicator has been set up by the World Business Council for Sustainable Development. (WBCSD 1999.)
- Key indicators and indicator systems: the publication of the 'headline indicators' by the Commission may be interpreted as another step towards one unique indicator for the environment which may become as accepted and meaningful as the GDP indicator for economic issues. Germany has already proposed the so-called 'DUX' as an aggregate indicator for Germany as a whole (UBA 1999). It is based on a collection of six indicators: climate, air, soil, water, energy and resources.

The development environmental indicators and their various applications are motivated by the need to have reliable aggregate information on environmental issues. If properly designed and based on reliable data, these indicators will provide facts in a condensed and readily understandable form. The need for such indicators will definitely grow in the future.

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Part III: International R & D developments

1. The United States: science and technology in the 'new economy'

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Summary

Science and research prospered in 1999. The technology-based 'new economy' was embraced alike by investors, political leaders, and the public. Public confidence in science remained high. Total R & D spending reached USD 247 billion, up 8.8 % over 1998, its growth continuing to outstrip GDP growth by a factor of two. Industry contributed the bulk of this increase and now funds almost 70 % of all R & D, although companies pressed for more efficiency in R & D and innovation. Congress approved a five-year extension of R & D tax credits. Other policy concerns in 1999 included cryptography controls, accountability in R & D, openness in academic and defence research, shortages of high-tech workers, and disciplinary imbalance in research.

1.1. Introduction

The year 1999 saw increased confidence in the reality of a technology-based 'new economy' in the United States. Investors, voters and the general public strongly supported science and technology because of their perceived value as the most important drivers of the economy and because they provided the tools and capabilities to solve national problems such as health, defence, and agriculture. The total investment in research and development (R & D) was up substantially. The federal government's portion of R & D funding continued to decrease, but its support of basic research, especially academic research, held firm. The policy environment for science and technology continued to be positive.

1.2. R & D funding trends

The United States is known for its lack of a formal science and technology policy. During the period following the Second World War, its de facto policy imperatives were derived by examining US government research and development (R & D) appropriations. One had to 'follow the money' to identify and understand the underlying policy elements.

Today, although it is as important as ever to follow the R & D money, there is a big difference in who pays the bills. As we enter the new century, the federal government's share of US R & D spending is projected to fall below 25 %. Industrial R & D is shaping science and technology policy in conjunction with technology and the global marketplace. The new economy has displaced federal agencies and Congressional appropriators as the predominant driving force guiding research priorities.

US R & D spending totalled USD 247 billion in 1999, according to preliminary figures released by the US National Science Foundation (NSF). This is an 8.8 % increase over the estimated total of USD 227 billion for 1998. Annual increases in total US R & D spending in recent years have been impressive. On an inflation-adjusted basis, they were 7.3 % for 1999, 6.2 % for 1998, and 5.7 % for 1997. These increases were about twice the real growth in gross domestic product (GDP), which ranged from 3.9 % in 1997 and 1998 to 2.4 % in 1999.

R & D as a share of US GDP increased to 2.8 % in 1999. This is about the same as the mid-1960s, the peak of modern US R & D spending as a percentage of the economy. Then, the emphasis was on federal spending for defence and space. Now, it is industry spending for new technology, driven by the high-tech sector of the economy. In 1999, industry funded 68.5 % of total R & D, the federal share was 26.7 %, and universities and other non-profit-making institutions provided about 5 %. Table 1 provides details for 1999 R & D expenditures by performing sector and source of funds.

Table 1: United States R & D in 1999

National expenditures for research and development, by performing sector and source of funds in 1999 (million current USD, preliminary figures)						
		Sources of funds (million USD)				
Performers	Total	Industry	Federal government	Universities and colleges	Other non-profit-making institutions	Per cent, by performer
	All R & D: basic research, applied research and development					
Industry	185 892	165 955	19937	—	—	75.3
Industry-administered FFRDCs	2166	—	2166	—	—	0.9
Federal government	17 362	—	17 362	—	—	7.0
Universities and colleges	28 256	2163	16 137	7923	2032	11.4
U & C-administered FFRDCs	6169	—	6169	—	—	2.5
Other non-profit-making institutions	6319	1194	3246	—	1880	2.6
Non-profit-making administered FFRDCs	836	—	836	—	—	0.3
Total	247 000	169 312	65 853	7923	3913	100.0
Per cent, by sources	100.0	68.5	26.7	3.2	1.6	—
	Basic research only					
Industry	11 778	10 888	890	—	—	29.3
Industry-administered FFRDCs	601	—	601	—	—	1.5
Federal government	3100	—	3100	—	—	7.7
Universities and colleges	18 758	1252	11 743	4586	1176	46.6
U & C-administered FFRDCs	3086	—	3086	—	—	7.7
Other non-profit-making institutions	2795	549	1494	—	752	6.9
Non-profit-making administered FFRDCs	107	—	107	—	—	0.3
Total	40 224	12 689	21 020	4586	1929	100.0
Per cent, by sources	100.0	31.5	52.3	11.4	4.8	—

NB: FFRDC = federally funded research and development centre; U & C = universities and colleges. State and local government support to industry is included in industry support for industry performance. State and local government support to U & C is included in U & C support for U & C performance.

Source: National Science Foundation, Division of Science Resources Studies. These data were derived from data collected in three SRS surveys: survey of industrial research and development, survey of research and development expenditures at universities and colleges, and survey of federal funds for research and development.

Federal government support of R & D has lagged behind inflation since the 1985 financial year (FY). This trend is expected to continue into the 2000 FY, in spite of a modest rise in the 1999 FY. Table 2 provides details for the 1999 FY, as compared with the previous year and projected figures for the 2000 FY.

Table 2: Federal R & D budget authority in the 1998–2000 financial years, by budget function.

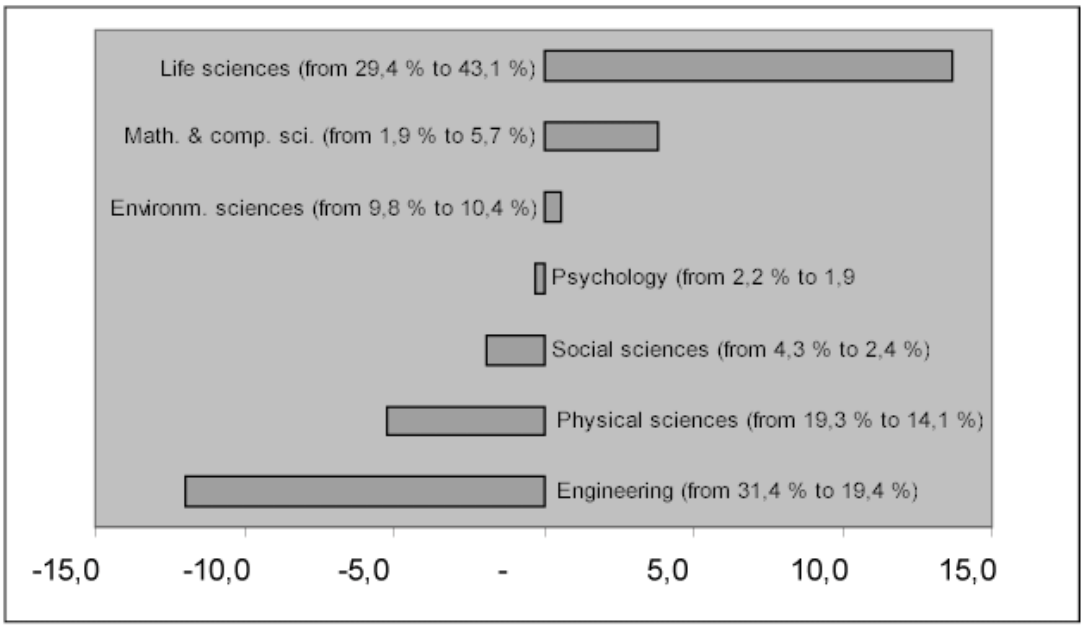
Budget function	Agencies' budget submissions			
	1998 FY (actual, billion current USD)	1999 FY (preliminary, billion current USD)	2000 FY (proposed, billion current USD)	Percentage change 1999–2000 FYs (constant USD)
National defence	39 823	40 387	37 710	– 8.5
Health	13 576	15 479	15 824	0.2
Space	8198	8239	8422	0.2
General science	4360	4739	4951	2.4
Natural resources and environment	1855	1928	1944	– 1.1
Other functions	5757	6114	5564	5.3
Total	73 569	76 886	75 415	– 3.8

NB: Data in this table reflect budget information collected through April 1999.
Source: Agencies' submissions to OMB via Circular No A-11, Max Schedule C; agency budget justification documents; and supplemental data obtained from agencies' budget offices.

Since the end of the cold war, there has been a substantial rearrangement of federal spending priorities for defence and other national missions. In the 1990 FY, 63 % of federal R & D spending was allocated to national defence; in the proposal for 2000 the share of defence is 50 %. The large reduction in spending for defence R & D following the end of the cold war was largely absorbed by very rapid increases in health research, which grew from 13 % in 1990 to 21 % in the proposal for 2000.

Changing federal R & D priorities have had dramatically different impacts on various fields of science and engineering. Engineering, the physical sciences and, to a lesser extent, the social sciences have been losers. The computer sciences and life sciences have been winners, while the environmental sciences and psychology have roughly held their own. Figure 1 shows these changes between 1970 and 1997.

Figure 1: Proportion of total federal funding given to each main field of research — Changes in percentages between 1970 and 1997



NB: Other sciences not classified within one of the broad fields listed in the figure are excluded. *Source:* National Science Foundation, Division of Science Resources Studies, survey of federal funds for research and development.

Globalisation of research has impacted federal patterns of support for research in several ways. First, average bench scientists doing research in university, government, and other laboratories are collaborating more. For 'ordinary science', this is hard to quantify since relevant data on international cooperation are not collected by most federal research agencies. Collaboration is increasing because the process of solving common problems benefits from synergistic relationships that combine common interests, unique talents, and state-of-the-art facilities located in different countries.

This increased collaboration is reflected in the scientific literature. Scientific papers co-authored by scientists from different institutions comprised about 50 % of the total in 1995. Almost 30 % of these publications involved international collaboration. The proportion of all papers published worldwide involving some degree of international co-authorship increased from 6 % in 1981 to 15 % in 1995.

1.2.1. Industry support of R & D

Spending on R & D by US industry has increased much faster than expected since the mid-1990s. During the previous decade (1985–94), the increase in industry support of R & D averaged just 2.8 % per year in real terms, only marginally better than the overall real growth of the economy during this period (2.4 %). In contrast to this anaemic performance, average growth in support of industrial R & D exceeded 9 % annually for the period 1995–99.

The robust condition of industrial R & D in the United States is demonstrated by Table 3. Note the 71 % increase in company-funded R & D over the five-year period from 1994 to 1999. In comparison, the federal support for research in industry actually decreased during this period in both current and real dollars.

Table 3: Industrial R & D 1994–99 — Sources of funds and R & D spending by category (billion current USD).

	Sources of funding for industrial R & D					
	1994	1995	1996	1997	1998 (1)	1999 (1)
Industry	97.1	108.6	121.0	133.6	148.0	166.0
Government	20.3	21.2	21.4	21.8	20.2	19.9
Total	117.4	129.8	142.4	155.4	168.2	185.9
	Industrial R & D spending by category					
Development	87.9	97.3	105.9	113.2	122.2	134.7
Applied research	23.0	26.9	29.0	32.4	35.5	39.4
Basic research	6.5	5.6	7.5	9.8	10.7	11.8

(1) Preliminary data.
Source: National Science Foundation.

One might expect that some of the increased funds for the development of new products and services would come through reductions in industry support for basic and applied research. The numbers tell a different story. Spending by industry for basic research increased by more than 80 % from 1994 to 1999. Applied research support increased by more than 70 %. As a percentage of the total industry R & D spending, basic research was virtually unchanged (6.4 % of total industry R & D in 1999 compared with 6.5 % in 1994) and the share that went to applied research decreased only slightly (21.2 % in 1999 compared with 23.0 % in 1994).

Why did basic and applied research hold their own compared with development during this period of increased emphasis on controlling costs and efficient development of new products and services? One reason is that some of the fastest-growing companies are in industry sectors such as biotechnology and pharmaceuticals whose new products are closely related to cutting-edge advances in some sectors of fundamental science.

The percentage of sales devoted to R & D and the rate of increase in company-funded R & D vary substantially between industry sectors. NSF data (1986–96) show the industrial sectors with the fastest growth in R & D expenditures to be: non-manufacturing (16.2 %); lumber, wood products and furniture (12.4 %); paper and allied products (7.6 %); and electrical equipment (4.3 %). Those industry sectors lagging were: stone, clay and glass products (– 9.7 %); primary metals (– 5.1 %); and petroleum refining and extraction (– 4.9 %). An apparent decline in R & D in the machinery sector, which includes computer and office equipment, was largely due to

the reclassification of several major firms with large R & D budgets from this sector to ‘computer software’.

What is most striking is the coming of age of R & D in the ‘non-manufacturing industries’, which include all service industries. The total R & D in this category is now the largest of all industry groups, whereas in 1986 it was the sixth largest. Its share of industrial R & D has increased from about 5 % to more than 25 % of the total. Four industry groups account for about 90 % of the non-manufacturing R & D expenditures: (i) computer-related services such as programming, data processing and surveying; (ii) wholesale and retail trade; (iii) communications services; and (iv) R & D and testing services.

The phenomenal increase in R & D in the services sector is illustrated by the data for computer-related services such as programming, data processing and surveying. In 1998, the companies in this subsector spent about USD 9 billion on R & D, an increase of 24 % over the previous year. Microsoft spent USD 2.5 billion in 1998, an increase of 30 % year to year. The Internet services’ part of this subsector (including companies such as America Online (AOL), Amazon.com and Yahoo) increased its R & D by 85 % from 1997 to 1998, to a total of USD 542 million. Amazon, AOL and Yahoo each increased R & D expenditures by over 200 %.

Although these figures are impressive, it should be emphasised that the data have many limitations. First, the latter are based on the classification of the firms that carry out the R & D. Firms are classified by the SIC (standard industrial classification) code. If the profile of a company’s sales changes from one year to the next such that a majority of its total sales falls into a different category, the firm’s SIC code changes and its R & D is shifted to the new category. Shifts also occur due to mergers, acquisitions and spin-offs. In recent years, the trend for these shifts has been from manufacturing to the services sector. It is also true that categories become out of date as the years pass, and decisions have to be made about changing them. The problem here is that historical year-to-year comparisons cannot be made for the new or revised categories (the time series comparisons are lost), so there are perpetual conflicts over whether and when changes should be made and, if they are made, what they should be.

1.3. Public attitudes towards S & T/R & D

Public attitudes towards science and technology remain favourable in the United States; 87 % of Americans felt the world was better off because of science in 1997 (5 % felt it was worse off). This compares with 88 % in 1988 and 88 % in 1957, the first time such a survey was made. Also in 1997, in response to a slightly different question, 75 % of Americans felt that the benefits of scientific research outweigh its harmful effects, while 12 % felt the harmful effects were greater than the benefits.

Public confidence in the leadership of organised science is high relative to other institutions. Although public confidence in most institutions in the United States has declined over the last 20 years, it has slightly increased for science. Only medicine

remains higher. Confidence in the leadership of science in 1997 was five times that of the US Congress, four times that of the executive branch of government, four times that of television, and 50 % higher than organised religion or education.

The US public is more supportive of science than those of other countries. This is largely because reservations about potential harm from science and technology are low in the United States compared with the public in other nations. Understanding of scientific terms and concepts by the public is also relatively high in the United States. The US public's understanding of scientific terms and concepts appears to be ahead of larger European countries. Based on a 1991 survey, Japan ranks near the bottom.

There is a strong correlation between level of education and attitudes towards scientific research in the United States. For example, among those Americans in 1997 who held a baccalaureate or higher degree, only 1 % felt harmful results outweighed benefits of research (down from 3 % in 1979). This compares with 5 % for high-school graduates and 3 % for those with less than a high-school diploma.

Substantial attention was focused on genetically modified food in 1999. It was the basis of trade disputes between the United States and the European Union, and the popular press covered the issue extensively.

Surveys of public attitudes towards biotechnology carried out in 1996 and 1997 in Europe and North America measure the public recognition of the potential benefits and risks from biotechnology. Dr Jon Miller of North-western University and colleagues in Europe and Canada have prepared an extensive analysis of these data, which will be published soon. Americans are more optimistic about the benefits of genetically modified organisms, while Europeans perceive the risks to be higher. The differences are surprisingly small. For example, when asked if genetically modified food is useful, about 64 % of Americans agree compared with 54 % of Europeans. As to whether genetically modified food is risky, 60 % of Europeans agree compared with 53 % of Americans. The roughly 10 % difference is less than would have been expected from reading press reports. Similar differences apply to opinions about genetically modified crops and medical applications of genetic technologies.

Positive perceptions towards biotechnology derive from several factors, some known and others unknown. Known factors include: (i) general technological optimism; (ii) belief in the general promise of biotechnology; and (iii) extent of interest in and knowledge about biotechnology issues.

1.4. Industrial R & D and the management of technology

Companies in the United States, as well as those in other nations, clearly have to move faster today to keep up technologically. This is documented by the R & D spending patterns presented in Section 1.2 above. The new realities of our technologically intensive economy have affected in several ways the corporations that support technology development and the researchers who carry out the R & D.

1.4.1. Increasing technological intensity

As R & D spending outpaces the growth of the overall economy, and government spending on R & D in industry decreases, the R & D/sales ratio for industry is increasing. In the United States, this ratio has more than doubled over the last 20 years from less than 2 % in 1978 to more than 4 % in 1998.

The technological intensity of various industry groups varies greatly and is reflected in the associated R & D/sales ratios. A survey of 1998 industrial R & D expenditures by 961 publicly held US companies reporting sales of at least USD 100 million and R & D expenses of at least USD 1 million showed that R & D comprised 4.4 % of sales. The drugs and medicines group spends a high proportion of its sales on R & D, 12.3 % in 1998. Biotechnology companies such as Amgen (24 %), Biogen (32 %), Immunex (49 %) and Centocar (60 %) are among the most aggressive spenders. R & D expenditures by the large, 'brand-name' pharmaceutical companies generally fall in the 8 to 16 % range.

Firms in a variety of 'high-tech' categories such as the Internet, computers, office equipment, electronic components and software have very wide variations in their R & D spending patterns. Examples of R & D/sales ratios in 1998 are: Lucent (17 %); Intel (10 %); Yahoo (20 %); Microsoft (17 %); Cisco (19 %); Dell (1.1 %); and IBM (5.5 %).

Many firms in 'old economy' companies are large investors in R & D. General Motors (5.0 % of sales) and Ford (4.4 % of sales) were the two companies with the largest total R & D budgets in 1998. They spent USD 7.9 billion and USD 6.3 billion respectively.

1.4.2. Getting the best technology at the lowest cost

Over the years, expenditures for R & D have kept pace with the rapidly growing profits of US companies. Although there are substantial variations in profits from year to year, R & D expenditures generally run about 50 % of total profits (50.1 % in 1998 for the 961 companies in the survey cited above). This is clearly a very large cost that managements of companies need to control. At the same time, companies recognise that they must acquire technology of a quality that will permit them to compete successfully in the world trading system.

Management of technology is becoming more effective and efficient. Top managers are more involved in developing the corporation's technology strategy and in measuring the results from those R & D investments. This has become a necessity because of rapid changes in the global marketplace that require quick responses — responses that often have a large technological component.

Technological competence is acquired more and more through alliances between companies or other sources of knowledge. Industrial researchers are shifting from full-time research to a combination of research and searching for relevant technology outside the corporation. The 'search to research' ratio is increasing.

The character of corporate alliances depends on the characteristics of the technology being developed or transferred. A distinction has developed between technologies that are strategic necessities and those that are strategic differentiators. Strategic necessities are the capabilities that all companies need to meet minimum global competitive standards in a particular line of business. The technology components can often be developed and maintained more cheaply through alliances, consortia, and joint ventures.

Strategic differentiators, on the other hand, provide distinctive marketplace advantages and are the basis of intense competition between companies. There is great reluctance to cooperate in technology development related to strategic differentiators, at least in the same market area.

The increase in the search to research ratio results in part from corporate outsourcing of technology. Technology is outsourced through purchase (such as turn-key plants or licensing of product or process patents), agreements between suppliers and original equipment manufacturers, cooperative research agreements between companies and universities or government laboratories, consortia of various types, and contracts with commercial research and development laboratories.

Outsourcing of research talent — hiring 'research temps' — is also increasing. The largest 'temp' agency in the United States specialising in scientists estimates that it has about 2500 researchers working temporarily in 60 laboratories daily. At the international level, there are a growing number of examples of outsourcing of corporate research support functions (routine testing, for example, or transcription services) to research professionals in low-wage countries.

There have been substantial changes in recent years in the industrial research environment and in the lifestyle of researchers. Companies have experienced dramatic shifts in their regulatory and business environments. These changes include mergers, government actions, and market changes driven by technological change. Mergers between large companies have tended to reduce total R & D.

The forces that have driven the globalisation of industrial R & D and reshaped industrial research laboratories have also changed the workplace for industrial R & D managers and researchers. The pace in the laboratory is faster, and directions change more often in order to track the shorter product development time lines. Research is more tightly directed, traditional informal tenure is less secure, and downsizing and mergers affect R & D staff just as much as other job categories.

How have these fundamental changes in the structure and performance of R & D affected funding patterns in the United States? One change is that industrial R & D has become much more global in recent years, as companies search more widely for the knowledge and know-how they need. Currently, US companies support an amount of R & D overseas equal to about 10 % of that they fund domestically. After a strong run-up, this percentage has remained more or less constant since the late 1980s. The total amount of this research has increased substantially and slightly faster than

domestic industrial R & D funding. Europe has been the major recipient of this support.

Foreign R & D spending in the United States has also grown. European-based companies provide the great majority of these R & D funds, just as US-based firms fund most of their overseas R & D in Europe. Currently, the corporate R & D flows between the United States and the rest of the world reflect a rough parity.

1.5. Special case of basic research

There has been strong bipartisan political support for federal support of basic research since the Second World War. In 1999, the federal government funded 52 % of all basic research. This represents a total of USD 21 billion, a 34 % increase over 1992 in current dollars (17 % increase in constant dollars). The National Science Foundation and the National Institute of Health (NHI) between them fund about 60 % of the federal share. Total federal funding of R & D actually decreased 5.5 % in constant dollars between 1992 and 1999 (in current dollars there was an increase from USD 61 billion to USD 66 billion). This makes the 17 % real increase for basic research support even more impressive. During this same period, funding of basic research by US companies increased from USD 7 billion to USD 13 billion. This represents an increase of 82 % (59 % increase in constant dollars). However, there seems little doubt that the character of the basic research funded by the NSF and NIH is substantially different from the 'directed basic research' found in industrial laboratories.

The proportion of total basic research in the United States that is funded by the federal government is decreasing. In 1992, it was 58 %. As noted above, it had decreased to 52 % in 1999. In addition to industry, universities and other non-profit-making organisations have substantially increased funding of basic research over this period.

Academic research increased to USD 19 billion in 1999, up about USD 1 billion from the previous year and USD 6 billion since 1992. This is a 45 % increase in current dollars (27 % increase in constant dollars). Industry support of basic research in universities went up by 34 % in constant dollars during the period 1992–99.

Debates have continued over the educational function of federal research support. Although there is general agreement that this support has resulted in a graduate education system second to none, there are also concerns that the high-pressure competition for grants and research leadership has undermined undergraduate teaching. This debate is not likely to be resolved to the satisfaction of all parties in the near future.

Megascience projects (very large, predominantly basic scientific research projects) are very different from ordinary science in the amount of government attention needed to assure effective and efficient collaboration. Some of these projects involve very expensive central facilities such as particle accelerators or neutron sources. Others,

such as global climate change, are associated with many geographic locations. Data are the glue that holds these ‘distributed megaprojects’ together.

Megascience projects generally are too expensive for any one country. Governments and the institutions of organised science are working towards better coordinated funding and management to prevent foolish things from happening. The successful examples of management of both distributed programmes and large research facilities in Europe, such as the European Organisation for Nuclear Research (CERN), serve as useful models. The OECD Megascience Forum has also made a good start in evaluating options for establishing more appropriate boundary conditions for these and similar projects in the future. It will be interesting to see if this initiative evolves into increased project-by-project cooperation, or whether a treaty or other durable agreement will emerge.

The foremost challenge remaining is to develop and implement a resilient, credible international framework for the support of megascience in the future. The recent US experience in cancelling the super-conducting supercollider (SSC) and subsequently funding the large hadron collider (LHC) has brought reality to the US megascience policy and may well contribute to meeting this challenge.

1.6. Value of R & D

Governments, companies and other institutions, such as charitable foundations and universities, support R & D because of its perceived value. This value may be financial, hence the trend in increasing industrial support for R & D. Governments fund R & D because of concerns over national defence, health, agriculture, and a variety of other concerns of their citizens.

Measures of and convictions about the value of R & D investments have changed and evolved over time. Twice in the last century, world wars have caused dramatic escalations in R & D spending for military purposes; the cold war resulted in another. The general public in the United States came away from these experiences with favourable attitudes towards and high expectations of science and technology.

Infectious diseases, such as smallpox and influenza, and other scourges like AIDS, cancer, cardiovascular diseases and schizophrenia have attracted large (and rapidly growing) R & D investments from both governments and companies. The public (government) portion of this investment ultimately reflects political decisions. These, in turn, depend on public attitudes towards the efficacy and safety of the results of science and technology.

1.6.1. National missions

National security, health, energy, standards, transportation and environmental protection are but a few of the national missions for which government agencies support R & D. In these and other cases, R & D is essential to the accomplishment of

the agencies' missions. In some countries, government support of R & D related to industrial development and trade is justified as part of industrial policy. This occurs in the United States as well, but mostly by indirect means. Spin-offs from space and defence R & D are examples. Overt programmes such as the Department of Commerce's advanced technology programme are few and poorly funded. This is not likely to change as long as the Republican control of Congress continues.

1.6.2. Economic return on R & D

Macroeconomic measures of the rate of return on R & D investments (the total of public and private) have been summarised in recent editions of *Science and engineering indicators,* published by the National Science Foundation, and in reports of the President's Council of Economic Advisers. These reports and others note that calculations of return on investment (ROI) in R & D vary widely, from 0 %to almost 150 %. The calculated ROIs depend on the methodology used and whether private or social ROIs are addressed. One widely quoted ROI in R & D of 28 % resulted from work by economist Edwin Mansfield of the University of Pennsylvania. Although the models used are not elegant and the resulting ROIs are uncertain, there is wide agreement that the return on investments in R & D is very high for society as a whole.

Indicators relating R & D and the economy include the following.

- R & D/sales ratio: a prime indicator of confidence in the efficacy of R & D to provide economic benefit at company level is the large and growing R & D/sales ratio. The important point here is the broad consensus between company executives and investors that R & D is not only important but crucial to the very existence of the company. This is reflected in their willingness to spend an increasing proportion of corporate resources for this purpose.

- Trade in technology: this consists of payments (such as royalties and licence fees) for intellectual property. The United States is the only nation in the world consistently running a large trade surplus in technology. For example, in 1996, the United States exported around USD 30 billion of technology and imported USD 7 billion. Domestic sales of technology together with foreign trade in technology generate large profits for some companies. They have launched major licensing sales campaigns and aggressively seek customers for at least portions of their technology. This is the other side of the 'buy or make' technology decisions faced by companies all over the world.

- Role of 'public research' in industry technology development: public research is playing an increasingly important role in patents granted by the US patent system. Public research refers to research performed by government, university and other non-profit-making laboratories, primarily funded by the federal government. The results of public research are in the public domain. Patent applications, which must include references to all 'prior art', are citing more and more research journal articles. In 1996, 25 % of all assigned patents (29 % of those from US inventors) cited one or more journal articles. US inventors overwhelmingly cited

US-authored papers. A large percentage of these citations came from papers other than industry-authored papers. For example, in ‘drugs and medicines’ 50 % of the science citations came from US public research. In contrast, only 17 % came from US industry research papers.

1.6.3. The ‘new economy’: fact, hype or both

For decades, the financial community has considered R & D expenditure as a strong indicator of future earnings growth and hence a measure of the appropriate price/earnings (P/E) ratio for the company’s stock. It is not surprising that high P/E ratios are most commonly associated with the stocks of high-technology companies. This marker for high P/E ratios is one of the traditional tools of the successful stock market investor.

There are indications that the stock market’s valuation of intangible capital resulting from R & D declined in the United States during the 1980s relative to tangible capital. During the 1990s, the hot market for technology stocks has almost certainly changed this. Other evidence indicates that the stock value of a company increases if the growth in sales resulting from the R & D is sufficiently greater than the cost of the research. In theory, this allows a company to fund an optimum level of research in order to maximise growth in stock price. Perhaps more valuable than these analytical approaches are experiences of individual firms. Companies with all or a large percentage of their sales from products that did not exist a few years ago easily recognise the pay-off from R & D.

The US economy has been acting out of character for several years. In late 1999, it neared a new record for the length of its expansion. Unemployment rates and inflation are both very low, which is an unusual combination. Consumer confidence is about as high as possible, and it is not unusual for consumers to spend more than they make. The stock market, especially the market for high-tech stocks, is off the charts.

The short explanation for this is that most of the credit is due to the global nature of the economy together with technology. Relatively free trade and cheap, rapid transportation technology assure alternative sources of supply and strong competition for companies, so they can raise prices only with great difficulty. Various kinds of technology, especially communication and information technologies, have oozed into every part of the economy relentlessly driving up productivity.

Many economists and astute investors have recently warned that this explanation is only partly true, and the economic ‘bubble’ will burst sooner or later, as it did in Japan a decade ago. They say that all of this ‘new economy hype’ will just make the fall harder. The new economy supporters, on the other hand, defend the unprecedented P/E ratios on the basis of technology. Alan Greenspan, Chairman of the Federal Reserve and the person given more credit than any other for current US prosperity, speaks almost poetically of the impact of technology on US productivity. He has noted that over the last 50 years the real value of the output of goods and services in the United States (the US gross domestic product — GDP) has more than

tripled. Yet, if you put today's GDP on a giant scale, and did the same for the GDP 50 years ago, they would weigh about the same. Greenspan explains this by noting that 'ideas don't weigh very much'.

Earlier in this chapter, it was noted that economic data should be carefully scrutinised and that conclusions based on them should be viewed with suspicion. One explanation of stock valuations in the new economy relates to inadequacies of conventional accounting, resulting in a substantial understating of companies' earnings. In the United States, investments by companies in 'intangible assets', such as software, marketing and computer training, are 'expensed' immediately rather than 'capitalised' over a period of some years. This results in earnings statements that appear lower than they would otherwise, and the P/E ratios of the companies' stock appear inflated. The *Wall Street Journal* has cited estimates that if R & D were treated as a regular capital investment (and inflation effects on inventories and depreciation were removed), the US market's P/E ratio would be only slightly higher today than it was in 1972, instead of its apparent increase of about 40 %.

How do the dynamics of the new economy differ from the old? A brief summary might be as follows. Knowledge has replaced capital as the basis of growth. Natural resources have long been largely irrelevant, since science and technology can be deployed to produce almost unlimited man-made resources at low cost. Knowledge and information (bits) are replacing physical objects in commerce (atoms).

The laws of supply and demand and of pricing and distribution have apparently been repealed for a rapidly growing portion of the economy. There one finds principles of increasing returns instead of diminishing returns. The first fax machine is worth little, but its value increases greatly if there are 100 million fax machines. The first copy of a software program may represent a very large R & D investment, and thus be very expensive. The marginal cost to the producer of duplicate copies, delivered to customers via Internet downloads, is almost zero. Knowledge-based industries certainly do have a different accounting dynamic from that of traditional industrial firms, even though this dynamic is imperfectly understood today. See, for example, the 1 January 2000 *Wall Street Journal* review of the new economy, 'So long, supply and demand'.

As noted above, the US public is favourably disposed towards science and technology; 80 % of the US public is confident that S & T will make their lives better. They readily accept new technologies and the changes that often accompany them better than do their counterparts in Europe and Japan. It would be interesting to know if this acceptance of technology and accompanying change is a key ingredient of the success of US high-tech entrepreneurship, as reflected by the high-flying stocks on the Nasdaq exchange.

1.7. What was new and important in 1999

The sections above discuss important S & T trends in the United States in 1999. Most are not exclusively 1999 events, rather part of a continuum. The year 1999 was noteworthy, in part, because important trends either became more apparent or were substantially better understood.

This is not to say that identifiable events of great importance to US science and to the policies that guide the development and health of science and technology did not occur. The year 1999 saw a lot of both. The magazine, *Science*, recognised its 'Breakthroughs of the Year' for the 11th year in a row. The 1999 winner was research identifying the extraordinary potential of human embryonic and foetal stem cells. Although much of this research was performed in the United States, more than 12 landmark papers (some co-authored internationally) were identified with the breakthrough. The nine runners-up in the *Science* breakthrough sweepstakes ran the gamut from the first photonic crystal laser to explaining the link between powerful gamma ray bursts and supernovas. Characteristically, the supernova results came from teams in Pasadena, Chicago and Amsterdam, emphasising again the lack of national exclusivity in research findings at the cutting edge.

In the preparation of this chapter, open-ended questions were posed to several dozen leaders in research and science policy as to the most important trends or events that helped shape the S & T landscape in 1999. The results of this unscientific poll form the basis of the discussion below.

1.7.1. Industry R & D

The dominance of industry in overall R & D funding in the United States was accompanied by a substantial increase in basic research support by industry. This trend, operative for several years, may be a leading indicator of a more 'science-intensive' industrial R & D scene in the future.

Internet growth and an explosion of e-commerce are the most visible evidence of the new economy. The importance of applying new business models along with new technology is recognised but not clearly understood in an operational sense. Merely applying new technologies to a flawed system results only in the capability to compound errors more rapidly.

Other 1999 industry R & D developments identified as important included:

- a greater utilisation of international benchmarking for technology and technology management;
- a growing backlash against genetically modified foods;
- an explosion in the availability of venture capital for high-tech start-ups, especially in the Internet sector;
- a re-examination of the role of anti-trust (competition) laws in the new economy (Microsoft case etc.);

- coping with shortages of high-tech workers, and related immigration issues;
- the effects on R & D of acceleration in corporate mergers and acquisitions, in a climate of increased deregulation;
- the effects of patenting research tools on the research enterprise, especially in the life sciences.

1.7.2. Research generally

The sequencing of chromosome 22, announced in December 1999, for the first time permits viewing the entire DNA of a human chromosome. It symbolises the emergence of a broad array of technical, ethical, and policy issues in advance of the projected completion of the 'Human genome' project in 2003. This was a model international project with US, UK, and Japanese participation. An international group of research institutions is coordinating an attack on several medical disorders involving chromosome 22. The many controversial policy issues related to sequencing the human genome include the role of the private sector, intellectual property questions, and issues related to genetic modifications of humans.

One concern of growing importance in academic science relates to the success of the Bayh-Dole Act, implemented in 1980. This federal law gives ownership of most intellectual property derived from federally supported R & D in universities to the researchers and their institutions. There is good and bad news. The good news is that universities receive hundreds of millions of dollars each year from their management of patents derived from federal R & D. At least one university president estimates that his institution will receive half its total revenue from intellectual property by 2020. The bad news is that these funds warp the motives of universities and faculties in profound ways, risking threats to the very openness of the academic enterprise. How this relates to the growing privatisation of educational activities generally remains to be seen.

Undergirding US R & D and its prosperity and efficiency is the continuing integration of telecommunications technology into the scientific enterprise. Its enhancement of international collaboration is obvious, but there are also many less visible impacts. These range from ubiquitous e-mail and faster and more efficient procurement of equipment and supplies via business-to-business e-commerce, to more efficient data exchange and preparation and editing of reports and journal publications. These changes, in turn, relate to the rapid evolution of electronic publication, both formal and informal. Complex intellectual property issues and antiquated 'paper publishing' business models cause concern to scientific and engineering societies and private publishers alike.

Other prominent trends in 1999 include:

- the synthesis of science, engineering and technology in common research programmes;

- the emergence of broader markets in higher education: markets for students, for faculty and for research; ‘for profit’ educational institutions compete with ‘non-profit-making’ institutions;
- anti-science feelings that pop up in surprising places: resistance to teaching evolution in schools; fear of genetically modified organisms; deconstructionist streaks in university social science and humanities faculties that deny all scientific objectivity; and animal rights activists who attack researchers and research institutions.

1.7.3. Government role in R & D

Although the federal government has ceded the field to industry as the dominant source of funding for R & D, the importance of the legal and political framework for the S & T enterprise is more evident than ever. It is hard to keep up with tax and regulatory issues related to the Internet, for example. As research and technology move with breathtaking speed, policy-makers have to move faster and work harder to balance the social, technological, and financial needs of society — a society which is increasingly global in its rules and constraints.

One theme currently emphasised in government R & D management and support is accountability, specifically in the Government Performance Results Act (GPRA) of 1993. It has been hard to apply credible, quantitative cost–benefit principles to R & D, but advances have been made. Agencies such as the NSF and NIH report progress. It remains to be seen whether the new GPRA tools go the way of earlier government management trends such as zero-based budgeting.

A lingering concern is the growing disciplinary imbalance in research supported by the federal government. The federal R & D budget was higher than almost anyone expected, reflecting a high level of general political support. Real increases for R & D in the Department of Defence mean that the physical sciences and engineering get some respite from budget shrinkage, especially as compared to biomedical research. Although this increase is small, it may presage better times ahead for these areas of research.

Other noteworthy 1999 events included the following.

- Extension of R & D tax credits for five years: this should, as House of Representatives Science Committee Chairman James Sensenbrenner stated, ‘put an end to the start-and-stop approach’ that accompanied single-year extensions for years.
- Database legislation, debated but not acted on, was deemed too generous by many researchers in its protection of commercial databases.
- Less openness in defence and nuclear research: this was demonstrated by increased security requirements at laboratories such as Los Alamos, and concerns that foreign-born researchers were unfairly treated.
- The unknown effects of the failed Kyoto climate conference and climate research controversies on environmental R & D.

- Continuing concerns about the role of S & T in foreign policy, met in part by the decision to appoint a science adviser in the State Department.
- Debate on control over high-tech exports for security reasons, especially cryptography.

1.8. Policy context and outlook for the future

The president, Congress, industry and the general public are all supportive of science and technology. This is reflected in the trends in public and private funding of R & D. The remarkable political consensus supporting substantial public funding of research has survived the end of the cold war. The divisions between Republicans and Democrats over increased federal support for generic R & D related to the needs of American industry have largely abated.

Congress continues its emphasis on basic research and the Administration speaks of technology initiatives that are decidedly basic in character. While President Clinton noted early in 2000 that 'science and technology have become the engine of our economic growth', he did so in the context of announcing major increases for academic science. The new national nanotechnology initiative should probably be called nanoscience, since its major aim is to build a strong research base and universities are its major beneficiaries. Overall, the Democratic Administration's shift from a science policy to a research and innovation policy, as seen by some observers, has been shaped by a Republican-controlled Congress. Congress has consistently exhibited its feelings that federal support for R & D should be generous but targeted on basic science and agency missions, and should not be an element of industrial policy. Neal Lane, the President's Science Adviser, supported this approach in stating that the federal role in nanotechnology is in long-term research not funded by industry.

Companies have voted with their wallets on the importance of R & D. Industry has not only increased its funding of basic research, but its leaders (through the Industrial Research Institute, for example) have also continued their support for increased government funding of research. In addition to favourable funding trends, industry was bolstered in 1999 with the five-year extension of tax credits for incremental R & D expenditures and generally supportive federal legal and regulatory actions related to research and technology. The Administration's aggressive stance with the European Union over trade in genetically modified food is one example.

The worrisome issue of imbalance between biomedical research and other fields, such as physics, chemistry and mathematics, received a lot of attention in 1999. Addressing this imbalance was of consideration in drafting the 2001 federal budget. NSF Director Rita Colwell stated early in 2000 that progress had been made in the president's budget proposals in rebalancing the federal research portfolio.

The 2001 financial year federal R & D budget request calls for healthy increases. For programmes representing the bulk of federal R & D, a USD 2.8 billion (7 %) increase

is proposed. The increase for the NSF is 17 %. Congressional reaction in January 2000 was favourable, although it is too early to tell whether the 'low ball' figure for the NIH (4.8 %) will be increased by Congress, and if it does whether this would be an 'add-on' or at the expense of other agency R & D budgets.

The outlook for industry R & D spending in 2000 is bullish. The annual *Battelle R & D Magazine* forecast estimates that industry will spend USD 197 billion on R & D, an increase of more than 10 % from the USD 169 billion estimated to have been spent in 1999. Federal expenditures will change little, USD 66.4 billion as against USD 65.9 billion. Total R & D spending in the United States is expected to increase by 8 % to USD 266 billion in 2000.

Campaigning for the 2000 presidential election got under way in earnest in 1999. Not unexpectedly, research was not a focus of the campaigns of any of the front-runners. All the leading candidates of both parties, however, are expected to be supporters of R & D funding and of a friendly legal and regulatory environment for research and technology.

1.9. Conclusion

In conclusion, 1999 was a good year for science and technology in the United States. The total R & D spending of USD 247 billion was up by 8.8 % on the USD 227 billion for 1998. The policy climate for science and technology, which is already very good, continued to improve as investors, company managers and the public associated research with the booming new economy. *Time Magazine's* selection of Albert Einstein as 'Person of the Century' reflected public enchantment with science and technology. It also increased the already high status of research and researchers in the United States.

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2. Japan: high-tech failures and bold policy initiatives

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Summary

In 1999, Japan recognised and addressed critical challenges in its science and technology infrastructure. Faced with high-technology failures that have shaken public confidence and growing faultiness in the science and technology system, the Japanese Government is rethinking its traditional government–industry–academia relationships. High-technology mishaps stimulated some of this self-examination and highlighted the growing need for educational and political reform. While scientific successes persist, they remain underutilised in the national economic structure. This, coupled with the downward trend in R & D intensity, spurred the government to create new policy-making mechanisms and adopt bold legislative initiatives. These actions include the creation of the prime minister's Industrial Competitiveness Council, the unification and restructuring of key ministries and aggressive initiatives to enhance university–private sector linkages, as well as to encourage widespread information technology diffusion.

2.1. Introduction

In 1999, Japan was shaken by a series of accidents and failures in high-technology fields. The ever-reliable *shinkansen* or bullet train railway experienced infrastructure failures, a major accident took place at the nuclear fuel processing facility in Tokaimura, and the H-II rocket failed twice. These mishaps fed lagging Japanese confidence in its high-tech system and fuelled shifts in both the public and private sectors towards careful analysis of Japan's science and technology policy. The collective government and private sector opinion is that in order for Japan to continue to grow economically, socially and politically, it must continue to focus on science and technology despite these setbacks. However, structural problems in Japanese society (in the educational, economic and political systems) must be resolved in order for science and technology to flourish.

In these circumstances, policy-makers are attempting to stimulate techno-economic development by strengthening university–industry linkages and enhancing IT penetration, in addition to promoting long-term educational and political reform. Importantly, the year 1999 posed the unanswered question of how to modify Japan's science and technology structure which appears to be getting caught up in a 'vicious circle' of lowered confidence and decreasing private sector research and development (Watanabe and Hemmert 1998; Wakabayashi et al. 1999).

2.2. Dealing with high-tech failures — Implications for policy

2.2.1. Tokaimura

There is an opinion that cost-cutting measures and efficiency-raising efforts aimed at competing with overseas rivals were the ultimate cause of the criticality accident that occurred at the Tokaimura uranium processing facility operated by JCO Co., a subsidiary of Sumitomo Metal Mining Co. (Shioya 2000). There is also the opposite view that there would have been no accident if the JCO management had conformed to sound economic principles (*Nihon Keizai Shimbun* 1999g; Shioya 2000). In the meantime, JCO, which was unable to compete in cost terms due to its outdated processing facilities, continued to survive thanks to the government's policy of protecting the domestic nuclear industry. The operation that caused the accident was being undertaken to fill an order by the Japan Nuclear Cycle Development Institute (formerly the Power Reactor and Nuclear Fuel Development Corp.). It involved fuel fabrication for the government's experimental test-breeder reactor, Joyo, and required more than six times the uranium-enrichment level needed for fuel for light-water reactors in use at power utilities. So the accident itself was linked to efforts in science and technology to improve nuclear reactor capabilities. Furthermore, the government order was a long-awaited 'rainstorm' in the midst of a 'drought', since JCO had been struggling with decreasing orders for commercial nuclear power plants.

It is strongly felt in Japan that for economic development it is essential to nurture domestic institutions and companies which command technological capabilities, without sacrificing economic efficiency. However, policy-based considerations seem to have allowed the survival of a company which had even lost the capability to ensure safety. The real implications for science and technology policy in the nuclear realm resonate with those arising from the other high-tech problems of 1999. Structurally, Japan is struggling with how to balance sophisticated science and technology policy in such a way that it stimulates research and development in the private sector, maintains strong academic and basic research capabilities in key areas and still encourages market dynamism. The very role of government intervention is called into question. The consequences have been hold-ups and delays while the government reviews and alters long-term nuclear power plant strategies and research. Several projects at nuclear recycling facilities and others under the programme for extracting plutonium from spent fuel have already been postponed. (*Nihon Keizai Shimbun* 1999g; Shioya 2000.)

2.2.2. Difficulties in the space programme

The successive failures of the H-II rocket have forced Japan to rethink its space development programme. According to the Chief Cabinet Secretary, Mikio Aoki, 'the repeated failures make a fundamental review of the current space development programme inevitable' (*Nihon Keizai Shimbun* 2000). The Science and Technology Agency (STA) has decided to discontinue the H-II rocket programme and concentrate instead on the H-IIA. Rocket Systems Corporation, the private company trying to create a business from satellite launches using the latest H-IIA rocket, has begun scaling back operations as commercialisation is pushed further into the future. Currently, it is cutting staff and streamlining itself. Consequently, the H-IIA rocket launch has been postponed until February 2001 leaving the company with no immediate source of income. (*Nihon Keizai Shimbun* 1999a, 1999b, 1999e, 2000.)

Prior to these setbacks, the National Aeronautics and Space Development Agency (NASDA) had experienced tremendous success over the last 30 years in developing domestic rockets and satellite technology even if they were not commercially viable. However, two satellite and two launch failures have seriously marred the agency's reputation, particularly in a culture where failure is intolerable. The real issue is understanding why the mishaps are occurring so regularly. One key is that over the last decade the NASDA budget has increased by 50 % while staff numbers have risen by only 14 %, suggesting that the agency is trying to do too much with too little. However, rather than increase the number of staff to achieve its original goals, employment is virtually at a standstill and the agency may actually contract. The problem is not just specific to NASDA, but is also the result of a decline in the number of science and technology graduates in Japan, particularly those with advanced degrees. (STA 1999a, 1999b.)

Further intensifying the review of the space programme is the recent failure of the M-5 rocket of the Institute of Space and Astronautical Science (ISAS). ISAS and NASDA are the government's primary space programme institutions, each with a

separate history and often overlapping projects (Griffy-Brown 1997; Griffy-Brown and Pike 1995). ISAS is overseen by the Ministry of Education, while NASDA falls under the STA. Both the STA and the Ministry of Education will merge in January 2001. Additionally, Mr Nakasone, who is currently the minister responsible for both the STA and the Ministry of Education, decided to integrate ISAS and NASDA into one comprehensive organisation responsible for Japan's space development. At this early stage, it remains uncertain as to how this latter merger will impact on science and technology policy in Japan. One thing which is certain is that both mergers come as a result of the policy-makers' desire to radically restructure Japan's science and technology policy system.

2.2.3. Railway issues

The famed *shinkansen* or bullet train railway has had trouble with slabs of concrete falling from tunnel walls on the Sanyo Shinkansen and other lines. It was subsequently discovered that the concrete used in Sanyo Shinkansen tunnels was made with improperly desalinated sea sand and consequently lacked sufficient strength. However, the problems were not confined to *shinkansen* tunnels, as elevated railways are also undergoing safety inspections. Japan's railway system has long been a symbol of the country's highly regarded and very real success in techno-economic development. These structural issues in the railway system are often seen as symbolic of structural issues currently facing Japan's science and technology policy system.

The old Japanese national railway (JNR) system used to be regarded as the pinnacle of Japan's civil engineering pyramid. Contractors who took part in JNR construction projects were said to have demonstrated 10 % or even 20 % higher performance than required by contract specifications (Shioya 1999). The situation began to change during the period of high economic growth, however, when more and more contractors met only 70 to 80 % of requirements. As government control loosened and the role of the private sector failed to establish itself solidly, the myth that the *shinkansen* was perfect prevailed, even though quality control was hindered by the structure of the Japanese construction industry. This industry involves complex and often shady relations among general contractors and a myriad of subcontractors. Furthermore, these complex relationships that characterise much of Japanese industry are one of the critical challenges which Japan seeks to address. However, institutional changes of this magnitude are both difficult and time-consuming, particularly in a society driven by consensus-style decision-making. Policy-makers are struggling with how to deal with this restructuring issue. (Wakabayashi et al. 1999.)

As in the case of NASDA and the problems with the nuclear energy programme, the railway problems reflect faultlines in the structure of the science and technology system. In particular, policy-makers are having to consider carefully how to develop a viable balance between the public and private sectors in science and technology areas that initially require enormous public sector support followed by solid, transparent, economically efficient private sector control. Deregulation seems to be a key issue, but the institutional capacity to avoid cronyism during the transition remains elusive. Nonetheless, continued scientific success does indicate that the ongoing policy restructuring and emphasis on basic research are yielding some positive results.

2.3. Success in 1999 and policy implications

Amidst the high-profile failures, during 1999 Japan's scientific community made remarkable strides, even in areas losing public support, such as the space programme. Most of these successes received little public recognition and noticeably little publicity compared with the failures. Some reasons for this are cultural, a tradition of keeping a low profile coupled with the sensationalism and humiliation of 'losing face' in the event of failure. Nevertheless, due to the bureaucratic long-term policy-making system, science and technology investment continued to increase steadily in 1999. The total annual budget includes science and technology promotion throughout all the ministries with the largest budget allocation typically going to the Ministry of Education (Monbusho) and the Science and Technology Agency, both of which often compete against each other (STA 1999a). The Ministry of Education budget increased by 2.9 % in 1999 and the STA budget by 4.3 %.

Some argue that continued funding only masks structural problems. However, the year 1999 seems to have seen significant attempts to remedy these problems. These successes show that there is considerable political imperative to trigger science and technology-related techno-economic growth by funding scientific research at universities and national laboratories regardless of public opinion. The question is how to appropriately connect this research to the marketplace.

Some significant scientific achievements include the following.

- University of Tokyo researchers (supported by the Monbusho) developed a laser semiconductor that emits blue light from the surface at room temperature, enabling it to be used to accelerate the reading and writing of digital videodiscs.
- The National Aeronautics Laboratory under the responsibility of the STA has successfully developed a prototype for a new propulsion system called the laser engine which converts solid fuel to plasma.
- A joint team from Tohoku University and the Ministry of International Trade and Industry (MITI) have created a zero-gravity environment for developing new materials.
- The Institute of Physical and Chemical Research (Riken) developed the world's fastest supercomputer which linked 2658 newly developed microchips, each of which can handle calculations 27 times faster than the microprocessors used in personal computers. The machine, which is currently being used in pharmaceutical development, is four times faster than the ASCI Option Red model at the Sandia National Laboratory in Albuquerque, New Mexico.
- The Electro-technical Laboratory and the National Institute for Advanced Interdisciplinary Research developed a new tunnel magnetoresistance element which has the potential to be a new magnetic-memory data storage medium.
- Researchers from the Science University of Tokyo have discovered a new cancer-fighting substance that inhibits the spread of cancer and strengthens the

effectiveness of other anti-cancer medications. (*Nihon Keizai Shimbun* 1999d, 1999e.)

Overall, the achievements are particularly remarkable considering that Japanese government R & D expenditures, even with significant increases over the last five years, remain far lower than those of other industrialised countries (STA 1999a). Japan's real challenge is to transfer these successes to the private sector. Meanwhile, the economy is struggling to emerge from a 'lost 10 years' since the collapse of the asset-inflated bubble and this is having an impact on private sector R & D spending, further provoking the need to make these transfers.

2.4. Addressing policy challenges

Until the middle of the 1980s, Japanese manufacturing industry's R & D intensity was far below the estimated levels for optimal techno-economic growth. This imbalance decreased due to consistent efforts to strengthen R & D investment. Consequently, Japan's manufacturing industry reached a reasonable level of R & D intensity at 2.8 % of GDP. (Watanabe 2000.)

However, this balance reversed again during the period of the 'bubble economy' when the actual R & D intensity changed to 5 % lower than levels estimated to be best for continued techno-economic growth. This imbalance grew after the bursting of the bubble economy resulting in the manufacturing industry's R & D intensity dropping to 1.9 % of GDP (Watanabe 1995, 2000). This low level of R & D intensity is the source of the current vicious circle between R & D and economic growth resulting in Japan's declining international competitiveness.

The critical challenge facing science and technology policy-makers in Japan is how to reverse this vicious circle and return to the positive or virtuous circle experienced earlier. This virtuous circle was characterised by greater R & D intensity followed by enhanced socio-economic returns that further fuelled investment. Addressing this challenge, policy changes in 1999 include: (i) the prime minister's initiative on the Industrial Competitiveness Council and the national strategy of industrial technology competitiveness; (ii) the strengthening of the ties between universities and industry; and (iii) a broad-based IT diffusion strategy.

2.4.1. The prime minister's initiative on competitiveness

In order to address the circumstances described, Prime Minister Keizo Obuchi set up the Industrial Competitiveness Council to improve Japan's international competitiveness. This council consists of all the ministers from relevant portfolios including ministers from the Ministry of International Trade and Industry, the STA, and the Ministries of Education, Posts and Telecommunications, and Finance, as well as chairmen of leading firms. This council was created intentionally to resemble the council in the Reagan Administration during the mid-1980s which published the 'Young report' and the 'New Young report'. This US council and its outcomes made

a significant contribution to improving the international competitiveness of US industry in the late 1980s and early 1990s.

At its June 1999 meeting, the Industrial Competitiveness Council decided to establish the national strategy of industrial technology competitiveness for 16 major industrial sectors. Under the administration of the National Industrial Technology Strategy Committee (chaired by Hiroyuki Yoshikawa, former President of Tokyo University), a draft strategy was summarised in December 1999. In this draft, strategies were devised to enhance linkages between universities and industry. Furthermore, this plan proposes to stimulate universities (rather than industry) to take the lead in disseminating innovative technologies into the marketplace. The new plan attempts to alter completely the traditional Japanese science and technology structure (JETRO 1999).

In addition, significant administrative reform is under way throughout the Japanese Government. Not only is the STA merging with the Monbusho, but the Agency for Industrial Science and Technology (AIST) in the MITI will no longer exist as the central institution for managing the MITI's R & D efforts. Instead, these R & D institutions are becoming independent entities managing their own R & D programmes. These changes are typical of the ongoing administrative reforms (*gyosei kaikaku)*.

It is important to understand this administrative reform in the context of deregulation. Deregulation (*kisei kanwa)* has required the Japanese to rethink their extensive network of formal and informal controls imposed on the economy. However, the emphasis is still on administrative reform rather than wholesale deregulation. Consequently, change has been incremental at best, as the nation continues to struggle with the cultural and political complexities of this process. For example, in many industrialised nations, the movement to revamp the government's economic role began with an emphasis on deregulation, focusing on increased competition and pointing to the benefits to consumers. In Japan, the concept of deregulation only came into being in the past five years and merely means the 'relaxation of regulation', a much less ambitious goal (Carlile 2000). Furthermore, the relaxation of regulation is eclipsed by administrative reform and primarily refers to selective market openings based on a combination of strategic concerns, the political clout of certain business factions, market factors, and pressure from foreign governments (Carlile 2000). In contrast to reform based on expanding consumer welfare, Japan's initiatives are based on the need to strengthen its international competitiveness. Therefore, the aim of deregulation in Japan is not to promote competition in order to reduce prices, but rather to relax regulations selectively when this increases the competitiveness of Japanese business (Carlile 2000).

2.4.2. Building stronger linkages between universities and industry

In response to the need to create new linkages between universities and industry, the Japan Patent Office (JPO) and MITI launched an ongoing series of legislative initiatives and programmes to promote more efficient technology transfer (Tsukamoto 1999a; JPO 2000). These initiatives focused on measures to promote technologically

oriented small and medium-sized enterprises and venture businesses, facilitating their access to university research. In preparation for these broad-based initiatives, a patent transfer database was organised. Additionally, 52 intellectual property centres were created in 44 regions throughout Japan to assist technopreneurs in accessing licensable intellectual property and technology transfer methods. These intellectual property centres now offer information on patents held by local universities and national laboratories in order to promote technology transfer to local companies. This is extremely important as almost 36 % of all Japanese researchers are employed in universities and colleges, accounting for approximately 20 % of Japan's total research and technology development expenditures (USD 120 billion) (JETRO 1999).

MITI-sponsored legislation has also been adopted to encourage the formation of academia–industry technology transfer businesses. These entities are similar to the technology licensing organisations (TLOs) that have been formed and widely used at many US universities. These organisations seek to transfer the research results of nationally and privately funded universities and colleges to local industries by assigning or licensing patents or other rights. While Japan has far to go in implementing and developing these technology transfer mechanisms, 10 TLOs have already been formed and are responsible for generating some successes (Tsukamoto 1999a, 1999b). Building on these programmes, legislation was adopted by the Japanese Diet that took further steps which included the following.

- Enhancing the environment for university research: in order to improve the poor infrastructure and facilities at most Japanese universities, as well as rectify the poor 'utilisation ratio' of the research generated there, measures were adopted to encourage private sector organisations to participate financially in the research programmes at public universities.
- Facilitating transfer of R & D from academia to industry: prior to this initiative, Japanese professors were highly restricted as to their ability to commercialise their research. This new legislation removes many of these restrictions and also allows TLOs to use more freely university campuses.
- Promoting the commercialisation of new technologies: in order to assist small and medium-sized enterprises, incentives have been developed to reward applied research results from Japanese universities. In addition, patent fees have been discounted for companies that meet certain requirements.
- Creating human resources that encourage innovation: programmes were developed to allow young researchers and scientists from universities and national laboratories to work jointly with the private sector in order to expand their ability to develop and commercialise new technologies.

2.4.3. Capturing the momentum of the digital revolution

Even though Japan is a leading producer of information and communication technology (ICT), it has a relatively low level of ICT diffusion. For example, the number of personal computers (PCs) per 100 white-collar workers is among the lowest in the OECD and the average number of PCs per 100 inhabitants in Japan is far below that of the United States (Griffy-Brown et al. 1999). Furthermore, while 40 % of US households have a PC, only 10 % of households in Japan own one.

Because of this weakness, the Japanese Government is promoting three key reforms: liberalisation, internationalisation and informatisation. The main thrust of liberalisation is the deregulation of the telecommunications and related markets. In this context, Japan has made a slow start, beginning with a revision of the NTT and Telecommunications Enterprise Law. In terms of internationalisation, the focus is on international movements related to electronic commerce as well as the global trend of integrating telecommunications and broadcasting. Informatisation has been centred on PCs and the Internet.

The Japanese Government recognised that there was a strong need to promote IT diffusion and solve some of the chronic science and technology problems related to the vicious R & D circle eroding its manufacturing industry. Consequently, in 1999, the government completely revised its guidelines, unified many of the agencies and restructured many of the ministries concerned. As indicated in these new guidelines, previous science and technology policy 'failed to take into account the incipient boom of electronic commerce' (Government of Japan 1999). The regulations in this regard are aimed at:

- institutional reform;
- increasing the use of IT and information literacy;
- establishing a network infrastructure;
- promoting basic and advanced R & D in this area.

The preliminary results of these policy changes are encouraging. Internet commerce in both the products and services markets doubled in 1999 (MPT 1999). While this is heartening, the trend in Japan still lags behind those of the United States and Europe. According to government reports, the biggest problem cited by users is the cost of connecting to the Internet (MPT 1999). The Japanese Internet service providers (ISPs), though much more expensive than their overseas counterparts, are relatively inexpensive compared with other services in Japan. The real issue is the cost of actually making a phone call to connect to the ISP, implying that the effects of deregulation policy (lowered service costs) have not yet reached the desired level. Furthermore, the Ministry of Posts and Telecommunications (MPT) does not anticipate that local telephone rates will be comparable to international rates until the end of 2001. As these costs are also born by R & D institutions, scientific laboratories and even the private sector, the desired network effects for enhancing science and technology are still a few years away.

One area of particular strength related to the Internet is Japan's growing capabilities in mobile Internet services. While PC penetration is lower than in many OECD countries, mobile services are among the world's highest (Griffy-Brown et al. 1999). Largely due to Japan's adherence to popular formats such as WAP and WideBand CDMA, some innovative companies such as Mobilephone Communications International (MTI) are world leaders in developing the Internet content for digital phones (Fulford 2000). This content is specifically designed to facilitate transmission and reception of web pages adapted for the smaller screens of mobile devices. While most mobile content is still geared towards the 'seedier' side of the Internet and not

yet integrated into the larger, more legitimate business-to-business e-commerce environment, it has tremendous potential in these other e-commerce areas.

Interestingly, this Internet strength in the mobile area in Japan highlights the US weakness in its lack of standardisation in the mobile phone market. The very deregulatory cacophony driving low telecommunications prices and booms in certain economic sectors has also tied the technology (particularly in business-to-consumer e-commerce) to personal computers rather than mobile phones. Some issues related to these technology choices are cultural: Japan is a cash-driven society where credit card use is relatively small. This being the case, different structures for electronic business transactions are established. In the mobile communications market, as in the rest of the telecommunications market, payment for services is usually deducted from a designated bank account with advance arrangements or paid monthly along with the phone bill. This is significantly different from the US market where the transaction is made at the point-of-sale by credit card. Consequently, the structures in Japan lend themselves more easily to the provision of content-driven services (easily facilitated by phone) rather than online purchases (more easily facilitated by PC). The dramatic growth in mobile communications in Japan bodes well for ongoing strengths in this technological area, particularly as mobile phone systems and services advance globally.

2.5. Conclusion and lessons for policy-makers

Science and technology policy in Japan has had legendary success in the past, but is currently struggling. A series of high-profile failures have marred Japan's high-tech reputation and negatively affected domestic confidence. However, it has not yet affected funding, and Japan continues to demonstrate a high degree of success in its scientific endeavours. More importantly, it has also galvanised the resolve of policy-makers to undertake significant structural changes including the restructuring and unification of key government agencies and even ministries. Furthermore, the year 1999 witnessed radical changes in policy attempting to stimulate greater university–industry linkages, previously considered largely irrelevant in Japan's national system of innovation. While science and technology funding has increased continually, policy-makers are having to consider carefully broader infrastructure and policy restructuring. Broader issues include revising the educational system and rethinking linkages between the government and the private sector (Motohashi 1999).

The key lessons for policy-makers include the following.

- Restructuring the relationships between the public and private sectors, as well as connecting academic research institutions to private firms, remains the key challenge for structuring science and technology in Japan.
- Balancing large science programmes with public support remains a critical challenge. The need for these programmes exists, but their mandate is eroded as economic pressures increase.

- Globalisation and the digital economy increase the pressure to create a low-cost IT infrastructure to support world-class science and technology. Late deregulation has significantly affected Japan's ability to compete in science and technology.

In 1999, Japan openly recognised and responded to significant challenges. Its key initiatives included the prime minister's Industrial Competitiveness Council, strengthening university and industry linkages under the national strategy for industrial technology competitiveness and enhancing IT diffusion across all sectors. Larger structural issues, such as restructuring the educational and political system, are ongoing and gaining momentum. However, these initiatives will take considerable time and their outcomes are still uncertain. Nonetheless, Japan is endeavouring to overcome the obstacles of 1999 and build on its existing strengths. Consequently, while Japan's overall competitiveness has decreased, it continues to demonstrate adeptness and persistence in dealing with the science and technology challenges it faces at the close of the 20th century.

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3. Russia: science and technology on the threshold of the 21st century

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Summary

Improving economic conditions and new policy measures enhanced the prospects of Russian RTD in 1999. One of the remaining problems is insufficient coordination between various stages of research and innovation activity. Consequently, support for networking and enhanced market orientation are some of the main goals of RTD cooperation between Russia and the European Unio. In the long term, hopes for sustained recovery rely on export-led growth and on intensifying investments on fixed capital and infrastructures. There are also early signs of an innovation-driven industrial recovery.

3.1. Introduction

In 1999, the Russian economy continued its recovery from the sharp financial crisis of August 1998. Due to the devaluation of the national currency, external trade declined significantly. In January–October 1999, the value of exports was just 81.1 % of the corresponding period of the preceding year. Imports declined even more sharply, to the level of 56.3 %. Domestic producers increased their market shares by producing substitutes for imported goods and consequently recovered after the incredible reduction in output in 1998. As a result, macroeconomic indicators turned for the better and, for example, industrial output grew by 7.8 % in January–November 1999 from the corresponding period of 1998. In some sectors such as chemicals and textiles, the growth was about 20 %. Economic growth helped to ease the strain on the government budget and even created positive expectations about the future of RTD and innovation in Russia.

These expectations were encouraged by the recent achievements of Russian researchers:

- a high-frequency generator based on the new principle of a super-light emission source;
- localisation of negatively charged eksitons in quantum holes, an achievement that can facilitate development of technical applications for quantum properties of matter;
- studies on water circulation in the northern Atlantic discovering intensive meridianal water and heat flows towards the north that affect future climate changes;
- a new area of underwater vulcanisation in the Atlantic Ocean allowing the modelling of geological peculiarities of the area, and making it possible to assess prospects for oil and gas extraction in the deep-water shelf that has not yet been explored;
- a distributed aerospace information system for identifying natural and technological disasters, and for monitoring environmental pollution, as well as agricultural, water and forest areas and volcanic activities, involving unique technologies for decoding information;
- a mobile system for the assessment of the stability of buildings and installations that helps to locate hidden construction defects, measure remaining safety margins and survey buildings in seismic areas;
- diagnostic methods for specific potato diseases;
- a low-toxic and fuel-saving gas bus engine;
- a new helicopter having low exhaust emissions and fuel costs;
- a new vaccine against animal helminthiasis;
- a new technology for manufacturing ceramic materials that are intended for non-ferrous metallurgy and high-temperature isolators and are extremely resistant to high temperature, fire and chemicals;

- the discovery of light-induced permanent magnetism in certain types of nanostructures.

One of the policy actions aiming to provide incentives for innovation was a draft law on innovation policy considered by Parliament in December 1999. Another new initiative involves the funding of innovation and industrial centres specialising in full-scale commercial production of competitive products that arise, for example, from the RTD efforts of small enterprises. Four such centres were started in information technology and electronics in 1999.

As a result of evaluation of research institutes of the Russian Academy of Sciences, 17 institutes were closed because they were outdated, and 22 research associations were established by combining smaller units. The motto for these new organisations is better coordination and stronger integration. They are designed to provide an integrated RTD and innovation infrastructure in strategic areas of STD and industrial development, and will benefit from earmarked government incentives. Institutes wishing to acquire the new status have to demonstrate success in earlier cooperation with industrial enterprises, banks, investment companies and universities. They should have expertise in training scientists and engineers, certification of products and services. National centres for research in humanities and joint STD and education centres, based on RTD units and universities, will also be established in 2000.

3.2. National RTD base: recovering or still shrinking?

Despite recent government initiatives, the 1990s as a whole were characterised by drastic falls in the main RTD input and output indicators. In 1996–97, for the first time since of the beginning this decade, some minor growth in gross domestic expenditure on RTD (GERD) was registered in the Russian Federation. In 1998, the unfavourable economic conditions aggravated the situation, and GERD expressed at constant prices was 7 % below that of the preceding year and accounted for just a quarter of the 1990 level, as can be seen in Table 1. However, preliminary estimates for 1999 show an increase in RTD expenditure of 11 % compared with 1998, bringing the expenditure back to the level of 1992.

RTD expenditure has lagged behind the main macroeconomic indicators, and the GERD/GDP ratio fell from 2.3 % in 1990 to 0.93 % in 1998. In 1991, this indicator was equal to the OECD average, but has since fallen to the level of such countries as Hungary, New Zealand, Poland and Spain. The fall is a troubling sign of the low level of RTD funding in Russia. At 1.04 %, the 1999 figure shows improvement but remains insufficient given the scale of the Russian RTD establishment.

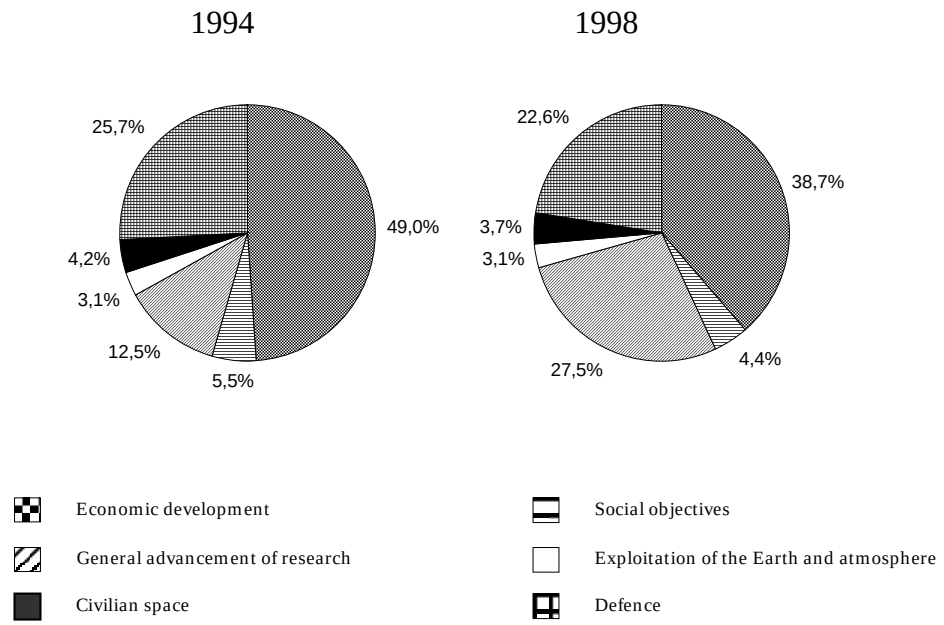
Table 1: Gross domestic expenditure on RTD (GERD) (million RUB)

	GERD at current prices	GERD at constant 1989 prices
1990	13.1	10.9
1991	20.0	7.3
1992	140.6	3.2
1993	1317.2	3.1
1994	5146.1	2.9
1995	12 149.5	2.4
1996	19 393.9	2.6
1997	24 449.7	3.0
1998	25 082.1	2.8
1999 ([1])	47 270.1	3.3

(1) Preliminary estimate.
Source: Centre for Science Research and Statistics (2000).

The decline in RTD intensity has been closely related to the sharp reductions in defence programmes and the conversion of the defence industry to civilian manufacturing. The proportion of defence-related RTD expenditures fell from 43 % of the total in 1991, to 26 % by the beginning of 1995, and to 23% in 1998 as shown in Figure 1. The proportion of research funding spent on defence RTD is in Russia approximately the same as in other nuclear powers such as the United States, the United Kingdom and France.

Figure 1: Percentage distribution of gross domestic expenditure on R & D by socio-economic objective, 1994 and 1998



Source: Centre for Science Research and Statistics (2000).

Among civilian objectives, those related to economic programmes prevail, though their proportion decreased from 49 % in 1994 to 39 % in 1998. This means that there was a weakening in industrial orientation of national RTD efforts. General advancement of research has been emphasised, and its share doubled between 1994 and 1998. The primary beneficiary was basic research carried out by the Russian Academy of Sciences and allied State scientific academies. Government budget allocations to the Russian Foundation for Basic Research also increased more than twofold. Social objectives, such as health and environment, consume a marginal part of Russian research funding and decreased even further from nearly 6 % in 1994 to 4 % in 1998.

The downsizing of Russian RTD in transition to the market economy has been accompanied by some changes in the sources of funding (Gokhberg 1999). Over the 1990s, government budget appropriations on RTD decreased to about one seventh, and their share of GERD was 54 % in 1998. At the same time, funding from the business enterprise sector accounted for one third of the total. However, the new pattern of RTD funding is mainly due to the fall in public financing rather than increases in RTD expenditures financed by enterprises. Private research funding has been discouraged by the generally unfavourable macroeconomic situation.

Another major shift in RTD financing has been the increasing role of foreign sources. It grew from a nearly non-existent level in the early 1990s to 10 % by the beginning of 1999. Three quarters of this amount was intended for RTD institutions in the business enterprise sector (e.g. those engaged in aerospace), and another 23 % for the government sector, primarily the Russian Academy of Sciences. Only 3 % of foreign RTD funding was acquired by universities. For many large RTD institutes that were formerly engaged in defence-related programmes, foreign contracts have provided the main basis for survival.

In contrast to the OECD countries, industrial RTD remained the greatest consumer of government funds in Russia. In 1998, the business enterprise sector acquired 57 % of all public RTD spending. The share of private investment in business enterprise RTD expenditure was 46 % — lower than in other European economies in transition or in the EU Member States. In industries specialising in exports and other relatively prosperous sectors, RTD financing was dominated by enterprise funds. In gas, oil, and chemicals, as well as ferrous and non-ferrous metallurgy, the share of public RTD expenditure varied between 1 and 20 %.

The number of RTD personnel declined to 855 200 at the end of 1998. According to our preliminary estimates, the number remained almost the same at the beginning of the year 2000. The intense outflow of young scientists to other occupations, combined with a negligible recruitment of newly educated scientists, created a situation in which 46 % of Russian researchers are more than 50 years of age. For advanced degree holders engaged in RTD, the percentages are even higher: for Masters of Science 57 % and for Doctors of Science 83 %.

3.3. Priority programmes for research

Shortages of financial resources have forced the government to attempt to increase the efficiency of public RTD by setting priority STD objectives. In 1998, an interdepartmental programme, entitled 'Prospects for STD in Russia', was initiated by the Ministry of Science and Technology, the Ministry of Economy, the Russian Academy of Sciences, and other public scientific bodies. The programme was coordinated by the Centre for Science Research and Statistics. One of its goals is to revise government priorities for STD in view of national socio-economic objectives. The programme is also going to map prospective basic and strategic applied research in areas which promise technological breakthroughs. In addition, world market niches for competitive Russian technologies are to be identified.

Principal priority STD areas, as defined by the programme, include information technology, industrial technologies and transport, new materials and chemical technologies, living systems technologies, power engineering, ecology and rational environmental management. Each priority area is further detailed into so-called 'critical technologies' of federal importance. Altogether, 52 critical technologies were listed for government approval. Basic research programmes emphasising physics, chemistry, life and earth sciences, and informatics are also considered a government priority.

Recently, the Centre for Science Research and Statistics carried out an evaluation of advances in priority technological areas. The evaluation showed that in some technologies Russia is at the leading edge of world research. Examples include space equipment, nuclear power generation, laser and plasma technologies, composites, life support and protection systems for humans in extreme conditions, and specialised technologies for the exploration and extraction of mineral resources. Some of these technologies have limited market potential or involve environmental risks, such as pipeline transportation of coal sludge or uranium mining in open deposits.

Important new research projects started in 1999 cover high-temperature synthesis of new materials that can resist chemicals, mechanical stress and high temperatures, neuron therapy of tumours, vacuum equipment for the large hadron collider, and high-capacity semiconductor laser diodes. A separate programme was set up to develop advanced scientific instruments.

3.4. Innovation and technology transfer

In 1998, only about 1200 industrial enterprises (or 5 % of the total) were engaged in technological innovation, i.e. introducing new competitive products and improving production technologies. Two thirds of innovative industrial enterprises were concentrated in just three sectors — machinery (37 %), food products (21 %), and chemicals (13 %). An increase in industrial innovation expenditure was registered in

1998 — for the first time in real terms during the 1990s. The 8 % increase was largely due to machinery, food and mining enterprises. The growth of industrial innovation expenditure outstripped the expansion of output, and the ratio of innovation expenditure to sales grew to 4 % in 1998. The corresponding figure was 2.9 % in 1995. The change is a small sign of a gradual shift towards innovation in Russian industry.

Foreign funding constituted 10 % of the total industrial innovation expenditures in 1998, and was twice as much as the share of the government. Foreign funding is especially important in mining (34 % of the innovation expenditure in the sector), and manufacturing of wood and paper products (19 %). In combination with machinery-building and chemicals, these sectors account for 93 % of foreign investment in technological innovation in Russian industry.

Despite the increased impact of foreign investment on innovation activity in Russia, innovation efforts still mostly target domestic markets. Russian innovative products have fared poorly on world markets outside the ex-USSR countries. While 14 % of innovating enterprises intended to export to the Commonwealth of Independent States (CIS) countries, only 5 % targeted Europe or South-East Asia and 3 % the United States and Canada.

It seems that enterprises do not always properly recognise factors that are hindering their innovation efforts. Difficulties are attributed to such economic factors as shortages of own funds, lack of public support, and the high cost of innovation. However, companies pay much less attention to ways of increasing their internal innovation capacities, for example strengthening in-house RTD capabilities, attracting qualified personnel, and improving organisational structures. Marketing research is also undervalued. Only 0.7 % of overall expenditure on technological innovation in Russian industry was allocated to marketing research in 1998. Technology transfer has not been promoted on an adequate scale. While about 500 industrial enterprises (42 % of innovating enterprises) were involved in the acquisition of new technologies in 1998, only 38 enterprises (3 %) were involved in technology transfer. All in all, these oversights in commercial innovation endanger the quality of innovations and hamper the creation and diffusion of competitive products.

Only a quarter of enterprises engaged in technology acquisition in 1998 purchased foreign technologies. Domestic technologies are cheaper, and language barriers too kept Russian enterprises oriented towards domestic RTD collaboration. The most common method in technology acquisition was the purchase of results of completed RTD projects. The acquisition of patents, licences, and know-how was much less widespread. The Russian technology market is dominated by unprotected technology, differing from the leading industrial nations where strict protection of intellectual property rights is the rule. Russian RTD units and enterprises are only starting to learn to operate in such an environment.

In 1998, a total of 501 technology transfer agreements were registered with foreign partners; 401 were transfers to and 100 imports from abroad. Most of the transactions involved RTD contracts or engineering and related services. Only 10 % of export agreements and 16 % of technology imports were transactions that involved patents,

non-patented inventions, patent licences, know-how, trademarks or industrial designs. The United States was the largest importer of Russian technologies (55 % of the total net value of technology exports from Russia), followed with a large gap by France (8 %), China (6 %), and Ukraine and Germany (4 % each). Technology was imported to Russia from the United States (22 % of the total net value of technology imports), Bulgaria (16 %), Germany (14 %), the Netherlands (11 %), Cyprus (8 %), Israel (7 %), Austria (4 %), and the UK (3 %).

In order to improve the existing system for protecting intellectual property rights, important measures were undertaken by the Russian Government in 1998–99. The Ministry of Science and Technology started a programme giving earmarked financial support to the patenting of results achieved in publicly funded RTD projects. Altogether, 136 inventions were selected for patenting in Russia, and another 37 for seeking patents in the international Patent Cooperation Treaty (PCT) system. All of the expenses were covered from the federal budget. In December 1999, a new competition was announced for RTD units, offering them federal funding for patenting STD achievements abroad.

In December 1999, the Russian Parliament discussed a draft federal law on innovation activity and State innovation policy. The law defines the objectives and principles of governmental support to innovation. One of the measures is the reservation of 1 % of budgetary funds intended for federal authorities for the financing of innovative projects. Such projects, aimed at developing competitive high-tech products, will be provided with additional funding and risk insurance from the so-called ‘budget for development’ — part of the federal budget intended for the financing and guaranteeing of investment projects.

3.5. International RTD cooperation

In 1999, the international RTD cooperation activities of Russia were aimed at increasing the efficiency of mutually beneficial collaboration with industrial nations and developing a common STD framework with the CIS countries.

A plan for State policy in international STD cooperation was prepared by the Ministry of Science and Technology. The document defines the objectives of STD cooperation with different groups of countries and mechanisms used in its public support. STD links with foreign countries are seen as efficient tools in increasing the competitiveness of the Russian economy, supporting its transition to innovation-based growth, and ensuring Russia’s participation in global integration processes in STD and high-tech manufacturing. Special emphasis is put on harmonisation of related legislation, procedures used in financing international RTD projects from the federal budget, and measures stimulating foreign investment in Russian STD and technology exports.

The establishment of foreign-related non-profit-making research centres and a list of international and national organisations whose grants to Russian scientists would be tax exempt were approved by the Ministry of Science and Technology. The latter group includes, for example, the European Commission, INTAS, CERN, the

European Science Foundation, the German Ministry of Education, Science, Research and Technology, the Max-Planck and Fraunhofer Societies, the UK Royal Society, and the National Centre for Scientific Research (CNRS) in France, as well as academies of science in many European countries. The list also covers various public agencies, private foundations, research centres and universities from the EU Member States, Canada, China, India, Japan, Korea and the United States.

Fruitful examples of recent collaborative STD efforts include joint Russia–US studies on geodynamics and seismology, the monitoring of water resources and new purification technologies (Russian–German projects 'Oka–Elba' and 'Volga–Rhein'). There has been wide-ranging collaboration in information technology, telecommunications, biotechnology, medicine and health research with the British, French, German, Indian, Japanese, Korean and US partners.

3.5.1. Collaboration with the EU

Russian cooperation with the EU is based on the partnership and cooperation agreement (PCA) that came into effect in December 1998. The agreement covers other issues as well as collaboration in science and technology. In addition, a specific EU–Russian Federation (RF) science and technology agreement regulating in detail the cooperation (such as intellectual property rights protection, tax/custom issues, etc.) has been prepared for signature in the near future.

The EU expects that cooperation projects have to create 'European added value', something that cannot be achieved at EU Member State or regional level. Cooperation with Russia has two elements: assistance and cooperation.

The Tacis (technical assistance to the Commonwealth of Independent States) programme emphasises assistance. It was launched in 1992 to foster the development of democratic societies and market-oriented economies by transferring western know-how taking into account the specific local situations and existing local expertise. For the time period 2000–06, a new 'regulation' has been implemented. It concentrates programme efforts into priority areas and puts added emphasis on industrial cooperation. Nuclear safety remains an important target. It is expected that the scope of the programme will be extended to such areas as the development of north-western Russia, nuclear decommissioning, waste disposal and reprocessing.

Tacis does not fund pure RTD projects; instead, it targets projects that benefit the economy by improving the national infrastructure. That is why the programme has assisted in the restructuring of the S & T sector so that it can better support the market-oriented economy. For this purpose, four innovation centres were set up in Tomsk, Novosibirsk, Samara and Zelenograd in a project known as 'S & T development in the Russian market economy'. The work is being continued in the project 'Innovation centres and scientific cities' that will assist the economic development of science cities. Obninsk and three additional cities which are to be selected in a competition will be pilot cases. Tacis funding has also supported legal aid requirements, venture funding and networking of small enterprises engaged in

research and innovation. The work has been carried out under the project 'Technical assistance to the Foundation for Assistance to Small Innovative Enterprises'.

Russia and the fifth framework programme of the EU

All specific programmes of the fifth framework programme (FP5) are open for Russian participation. However, there is generally no funding available from the EU side to the Russian project partners, since Russia (unlike Switzerland and Israel) does not have an association agreement and does not contribute to the RTD budget of the EU. A Russian partner can receive funding support only if the Russian contribution is a key element in a joint project without which it would be impossible to execute the project successfully.

One of the horizontal programmes of FP5 is 'Confirming the international role of Community research' (INCO 2). Two of its sub-programmes, Copernicus 2 and INTAS, provide funding for RTD cooperation with Russia.

Copernicus 2 supports applied research activities. Due to the relatively low budget of EUR 28 million provided by FP5 for the years 1999–2002, only a single call for proposals was launched in 1999. Of the 202 proposals received, 72 were evaluated positively, and 62 of them had participants from Russia. For the remaining years of FP5, even if there is no further main call, Copernicus 2 support will be given for 'Accompanying measures' including 'Awareness and training measures' and a 'Conference scheme support' in order to develop RTD-related infrastructure and to stimulate cooperation.

INTAS (International Association for the Promotion of Cooperation with the Scientists from the CIS) predominantly supports basic research in a wide range of scientific disciplines. The strength of INTAS is that it cooperates closely with the Russian Foundation for Basic Research (RFBR). The cooperation is directly established with individual scientists, avoiding complications that often occur when large administrations are involved. The INTAS membership comprises the EU Member States, the European Commission, Iceland, Israel, Norway and Switzerland.

The overall budget of INTAS for the duration of the fifth framework programme is EUR 75 million, of which EUR 70 million is provided from the INCO programme of FP5. Usually about 80 % of funding of a project goes to the Russian and 20 % to the western partner. In 1999, INTAS launched an open call for proposals and three joint calls for proposals with CERN, the European Space Agency (ESA) and the Airbus industry. In total, 207 new projects were approved with a funding of EUR 16.9 million.

As there will be no further main calls from the Copernicus 2 programme for applied research, during the next few years the Russian demand for enhanced industry-related RTD cooperation cannot be sufficiently fulfilled within the FP5. What the EU can offer is only cooperation funded by the INTAS programme, and that is oriented mainly towards basic research. Therefore, a possible reorientation of the FP5 collaboration should be considered, putting more emphasis on industry-related RTD. During the planning stages of the next framework programme, an improved balance between basic and applied RTD cooperation could be discussed.

The Tacis programme also provides EU funding for the International Science and Technology Centre (ISTC) in Moscow. The ISTC was founded in 1992 as an international organisation by the Russian Federation, the United States, Japan and the EU. At present, members also include Finland, Sweden, South Korea and several CIS countries. Due to its non-proliferation objectives, the centre provides former weapons scientists with funds that can be used for civilian and commercial scientific research.

By October 1999, the ISTC had given EUR 230 million to more than 800 projects involving about 24 000 project participants. Annual funding is about EUR 30 million; in 1998, the funding amounted to about EUR 35 million, of which the EU contributed 49.8 % and the United States 32.5 %. In the partnership programme, private industry, governmental, non-governmental, and intergovernmental organisations can set up civilian RTD projects taking advantage of the infrastructure of the ISTC. American and Japanese companies are well represented in this programme, but European companies seem to prefer bilateral collaboration schemes.

Recently, Philippe Busquin, the Member of the European Commission responsible for research, proposed an initiative to form a 'European research area' because 'national research policies and Union policy overlap without forming a coherent whole' (European Commission 2000: 7). To overcome fragmentation and isolation, an integrating European policy is needed and this can only be achieved by improved concertation actions. Similar measures would be useful on the Russian side where coordination of the different RTD actions is not well developed. It could be beneficial for both the EU and Russia if Russia were to be effectively included in the future 'European research area'.

3.6. Conclusion

A strong S & T sector is a necessity for a national economy that hopes to flourish in the global market. Russia has untapped RTD treasures particularly in closed or former closed cities, science cities and former industry branch institutes. Russian RTD results are often very original because there was little exchange of information between the former Soviet S & T community and the rest of the world. Cooperation between Russia and the EU can bring together elements that complement each other, such as advanced electronics and microtechnologies from the EU side and modelling, aerospace, materials and nuclear know-how from the Russian side.

The brain drain remains a problem in Russia (Gokhberg et al. 2000). Large numbers of highly qualified scientists leave the S & T sector each year to emigrate to other countries, preferably the United States, or to move to other sectors of the economy ('the brain switch'). It has been claimed that the value of lost education and intellectual property amounts to hundreds of billions of euro. Russia is losing a strategic resource for the 21st century.

Another problem is weak innovation activity. It would be important for the government to become an efficient mediator between the RTD sector and industry, and to ensure coordination of innovation and industrial activities. That is why the

most important task that the EU should support is the establishment of links and networks between the different RTD actors. This has to be done by the Russians, but it could be assisted by the EU. Networking is particularly important because the Russian RTD sector has lost nearly all its original clients due to the decay of defence and civilian industries. The networks could be developed so as to make them compatible with their western counterparts, with which they should eventually be linked. Connections with western networks could provide support over the next few years until the recovery of Russian industry is sufficiently strong to drive national demand for RTD.

The relatively low interest of the younger generation in science, and their reluctance to begin hard scientific study that may in the end not be rewarding compared with other careers, is also a problem that may be alleviated in cooperation with the EU.

At present, prerequisites for sustainable demand for RTD and innovation do not exist. Fixed capital investment was greatly discouraged by the macroeconomic disequilibrium of the 1990s, and increased by only 2 % during the first nine months of 1999 compared with the corresponding period of the previous year. Monthly output growth was slowing down towards the end of the year, signalling gradual exhaustion of economic potential that had resulted from the reduction of imports.

On the threshold of the 21st century, three possible scenarios can be presented schematically for the next 10 to 15 years.

- The path of inertia marked by extremely low investment intensity, concentration of revenues to the raw material sectors and the outflow of currency abroad: in this case, further degradation of manufacturing industries, stagnation of domestic demand at a low level and deepening of budget deficits are inevitable. The consequences for the RTD sector are obvious given the absence of private investment in technology and innovation, and reduced prospects for RTD support from the federal budget.
- Export-oriented growth driven by exporting industries (fuel and energy producers, metallurgy and chemicals): to increase their output, enterprises of these sectors will require modernisation of their operations and supporting infrastructures (geological prospecting, machinery-building, construction, transport, etc.). Related RTD and innovation activities will be required. As its tax income increases, the government will be able to maintain the financing of basic research at a certain level.
- Investment-based growth relying on intensification of investment in fixed capital: according to some estimates it could be possible to increase investment by 7 to 10 % of GDP in 2005 and by 13 to 16 % of GDP in 2010. It would be essential to rely on the advantages that are offered by the still strong high-tech capacities of innovative machinery-building enterprises concentrated largely in the defence industry. This could make it possible to meet investment requirements with domestically produced machinery and equipment. The demand for innovation and RTD would be increased, initially in the form of contracts for development projects of adaptive character, incremental innovation, renovation of equipment, etc. Later, while moving along the path of innovation-oriented growth, the

demand for longer-term applied research would also rise. Opportunities to increase public financing of basic research would also improve.

For various economic, social and political reasons and limitations, it is unlikely that future development will closely follow any single one of the proposed trajectories. Instead, there will be a mix of features from the different scenarios. Nevertheless, it is obvious that an effective and energetic STD policy is urgently required before the anticipated growth in innovation and investment will take place. Otherwise, the deterioration of the RTD base may reach a scale that will significantly increase the cost of an eventual transition from a low-innovation trajectory to a higher one, or even make such a transition impossible.

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4. China: a restricted welcome to the knowledge economy

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Summary

China is eager to take full advantage of the emerging knowledge economy, but is less willing to allow the free flow of ideas among its citizens and from abroad. In 1999, the number of people able to use the Internet grew rapidly in China. Yet the country sought to restrict foreign influences by continuing its policy of prohibiting foreign investment in Chinese Internet service providers. At the same time, China made great strides in developing and commercialising computer and mobile phone technologies. While China has welcomed foreign high-technology companies and enacted legislation protecting intellectual property, there is still some concern about the implementation of these policies in practice. The emerging indigenous technological prowess of China was demonstrated in 1999 by the widespread use of genetically modified crops and the successful testing of a space capsule technology that is intended to be used in future manned flights.

4.1. Introduction

The year 1999 marked 50 years of existence of the People's Republic of China and it is salutary to reflect on the changes that have brought China to its position as a world power. The pace of change has accelerated in the past decade as China has modified its ideological stance to create a 'socialist market economy'. A major driving force has been the development of an efficient science and technology (S & T) system.

Since 1978, China has encouraged experimentation in its S & T system as a means of arriving at reforms and has periodically summarised the main directions of reform in authoritative decisions of the State Council and of the Communist Party of China. Two significant decisions were the March 1985 decision on the reform of the science and technology management system and the May 1995 decision on accelerating scientific and technological progress. Such decisions have constituted a creative way of approaching a complex set of issues by allowing considerable freedom for experimentation. This stimulation of local experiments has been one of the strengths of the Chinese approach to reform of their S & T system. A detailed account of the reforms stemming from these decisions has been given in the report of a recent international mission (IDRC 1997). Stemming from this, attention has been directed to the development of a national innovation system (Lu and Lazonick 1999) and of a national strategy for international collaboration.

In 1999, the impetus was maintained in the August decision on encouraging technological innovation, developing high technology and realising commercialisation of new technologies. This decision recognises the importance of the knowledge economy and of the need for China to develop high-technology industries based on commercialisation of R & D in areas such as information technology, biotechnology, new materials and high-tech agriculture. The decision emphasises that 'innovation is the soul of a nation's progress and impetus of a country's prosperity'. Both State-owned and private firms are highlighted as the main drivers of innovation. Continued reform of the S & T system is a critical factor in developing an innovative culture by forcing engineers and scientists in the State research system into industry. While continued input of overseas technology is seen as essential, emphasis is placed on commercialising Chinese S & T and new fiscal measures are proposed to assist technology-based start-up companies.

The role of the services sector has been recognised and the concept of integrated manufacturing/service firms is gaining ground. The issue of improved networking between S & T institutions and industry is emphasised in the August 1999 decision and collaboration between firms is recognised as being an important factor in innovation. The role of technology parks is reinforced with emphasis on making them catalysts for university–industry collaboration.

In support of these thrusts, the S & T budget was increased by about 10 % in 1998 to EUR 13.8 billion of which 43 % was spent on R & D. (The exchange rate of CNY 9.4

against the euro is used in this chapter, although towards the end of the year the euro declined to about CNY 8.3.) Compared with other countries in the region, the Chinese R & D expenditure is still a small fraction of GDP at 0.69 % (cf. Japan at 2.92 % and South Korea at 2.89 %). The small R & D expenditure is reflected in the relatively low R & D intensity of Chinese industries when compared with OECD countries. Thus for 22 industry sectors ranging from aeronautics and computers at the high end to textile and clothing, and wood and furniture at the low end, in 1995 the average R & D intensity in China was 1.15 % compared with 7.84 % in OECD countries (Sheehan and Sun 1999). The 1999 R & D expenditure data are not yet available, but it is probable that the steady growth since 1996 has been maintained.

In line with the intent of the May 1995 decision, a knowledge innovation project was launched at the end of 1998 with the aim of increasing China's competitiveness to the world's top 10 before 2010. An investment of EUR 0.5 billion was earmarked until 2000 to start the programme.

A massive reform of China's S & T system to better link S & T to commercialisation has been in progress over the past decade (IDRC 1997) and will continue following the August 1999 decision. Thus, in 1999, it was decided that some 240 scientific and technological research institutes would face comprehensive reorganisation. About 170 institutes would be turned into commercial laboratories and the rest would become technological enterprises or educational establishments (*Financial Times* 1999a).

4.2. New thrusts of reform in the Chinese Academy of Sciences

A major component of the national innovation system is the Chinese Academy of Sciences (CAS) which has been extensively reformed over the past decade (IDRC 1997). CAS plans to have 100 internationally renowned scientific research institutions and 20 interdisciplinary and interregional research centres by 2005.

During 1999, CAS continued its reform process through the new pilot programme of the 'Knowledge innovation' project. Resources have been focused on the following nine areas: new and high technologies of agriculture, population and health, information and automation, energy sources, ecology and the environment, space science and technology, new materials, geoscience and other cross-disciplinary areas. Two policy initiatives support these focus areas: rationalisation of scientific institutes and 'picking winners'.

The rationalisation of scientific institutes involves the creation of a number of R & D bases where existing CAS institutes and other institutes within a city are combined with strong support from local government to form a focus for local high-tech industry. Thus, in Shanghai, two R & D bases have been formed. In July 1999, the Base on Life Sciences having about 1000 researchers was opened; it will cover super-high-yielding crops, key diseases and population control, neurobiology, biological macromolecular structures, and human genome research. The Base on High Technology will cover materials science, informatics, infrared and laser technology, and space technology. Similar rationalisation is planned in Beijing, Xinjiang and

Dalian. As an indication of the changes, the CAS Institute of Computing Technology in Beijing will downsize from about 1000 staff to around 100, with the rest transferred to the Legend Group, the largest PC firm in China, and other companies. The new institute will devote 20 % of its resources to basic research, 30 % to strategic research to support national needs and 50 % to new products and technologies.

The policy of 'picking winners' is based on selecting projects with potential for short-term (two to three years) breakthroughs. Projects include applications of industrial robots, fuel cells, broadband IP networks, small satellites, rice genetics and agro-technology. Altogether, 15 topics have been identified for selective funding after extensive consultation.

4.3. Shortage of R & D manpower

Although world-class science and education facilities exist in China and others are being created, there is a problem with the adequacy of the S & T workforce.

While the overall number of people engaged in S & T activities in China appears large at 2.81 million, of which 0.75 million are engaged in R & D, the relative intensity in terms of population is low. Thus only 7 per 10 000 are engaged in R & D. This is well below the number required to develop the indigenous capability to sustain innovation and develop the economy. OECD data suggest that about 35 to 40 researchers per 10 000 of population is a minimum figure for an innovative high-income economy. In Japan, the figure is 100, Korea 48 and in Taiwan 70 per 10 000. China still has a long way to go. (Tegart 1999.)

China has recognised the need to increase the number of researchers in order to develop a knowledge economy. The new CAS R & D bases will foster the training of researchers in China, while a continuing scholarship programme will send promising young people abroad to study. Roughly two thirds of people sent abroad have returned after completion of their studies and CAS has launched an aggressive 'Hundred talents' campaign to bring back more. CAS will also recruit 300 top overseas scientists to work on programmes of the 'Knowledge innovation' project. Some EUR 64 million has been allocated for this purpose with each scientist allocated EUR 0.2 million as a research budget.

4.4. Developments in selected areas of technology in 1999

4.4.1. Information and communication technology (ICT)

One of the significant developments in ICT technology in 1999 was the growth of Internet use in China (Lawrence 1999). According to official estimates, about 4 million people were online by the end of June 1999. In the first six months of the year, Internet use almost doubled and the rate of growth continued during the rest of the year. According to a survey published in December 1999, there were 8.9 million

registered users of the Internet in China, and 86 % of them were between 18 and 35 years of age, many of them students. The number of users is projected to grow to 16 million in 2003 in line with growth elsewhere in the region.

The Chinese Government is in a dilemma over the Internet. On the one hand, it sees the Internet as a key factor in developing an innovative culture and economic competitiveness with a massive potential for developing electronic commerce. On the other hand, it sees the Internet as challenging government policy and control of information. Thus, in September 1999, the government reaffirmed a long-standing ban on foreign investment in Chinese Internet service providers. The government's ambivalence could benefit Taiwan and Hong Kong, which are more open to foreign investment.

The success of Chinese firms in supplying domestic markets with computers and telecommunications was noted in the previous TECA report (Lu and Lazonick 1999). The market in China remains huge — the overall penetration of mobile phones is still low at 2 % and fixed line phones at 8.5 %. In urban areas, the figures are much higher, but Chinese cities still lag behind Hong Kong where the penetration is 40.3 % for mobiles and 54.3 % for fixed line phones. An indication of the potential rate of growth in China can be gained from Taiwan, where the penetration of mobile phones went from 4 to 15 % between mid-1996 and mid-1999.

China's production of electronic goods has now reached the top rank in the world with annual production of 2.9 million computers, 32.7 million colour television sets and 10.2 million mobile phones. Significant Chinese innovations are now incorporated into such equipment and young Chinese firms are challenging foreign firms such as Motorola, Ericsson and Nokia. An example is Huawei Technologies which has a highly educated workforce of 9000, of whom about one half are engaged in R & D (*Financial Times* 1999b).

The major ICT production facilities are in the coastal provinces, which have 40 % of the population, employ over 50 % of China's engineers, and are responsible for over 60 % of the country's technological development expenditure and 50 % of R & D expenditure (Grewal and Sun 1999). Over recent years, regional divergence in high-tech capability and per capita income has been increasing between the coastal, central and western provinces.

In 1998, Chinese exports of ICT products reached EUR 14 billion against imports of EUR 12 billion. However, electronics exports amounted to only about EUR 3 billion compared with imports of EUR 8 billion reflecting China's dependence on Japan, Korea and Taiwan for advanced electronic components. A significant breakthrough was achieved in Yugoslavia with a contract for supply of a GSM mobile telecommunications system worth EUR 230 million. China seized the opportunity offered by the western embargo on trade with Yugoslavia.

China's prospects for growth in the ICT sector are very good.

4.4.2. Agricultural biotechnology

China has embraced the use of genetic engineering to increase crop yields and has carried out research since the 1970s. Transgenic soya and corn crops have been extensively planted and, in 1999, transgenic hybrid rice with built-in pesticide resistance was extensively planted in paddy fields. In contrast to the situation in Europe, the United States and Australia, there appears to be no public debate on genetically modified foods. This is somewhat surprising since genetically modified crops are likely to speed up structural change in agriculture and food supply, making it more difficult for smaller producers to stay on the land. The major debate on genetic engineering in 1999 was on the potential use of Chinese human genetic material by foreigners and export has now been prohibited (Dan and Lei 1999).

Agriculture remains China's most important economic sector and accounts for about 20 % of GDP and over 50 % of employment. With only 7 % of the world's arable land, China has been responsible for feeding about 20 % of the world's people. The performance of this sector is vital to China's food security and has been given the highest priority in planning.

The importance of a more efficient modern agricultural system was emphasised in the May 1995 decision and was reinforced in August 1999. The complex, multilayered agricultural research system, with its duplication at State, province and district levels, has already been streamlined (IDRC 1997). The August 1999 decision recognises that in the global knowledge economy it is essential to combine information technology, biotechnology and traditional techniques to create an agro-industry that is capable of adding value to raw materials through an integrated production/services approach.

Over the past 30 years, investments in research have been responsible for 20 % of the total increase in agricultural productivity. In 1998, the 'Harvest' programme raised output levels in agriculture, forestry and fisheries. About one third of the EUR 7.5 billion increase was attributed to the results of research.

There is still a long way to go in creating modern agro-industry complexes in China.

4.4.3. Environmental technology

In recent years, environmental degradation due to the combined effects of rapid industrialisation, increasing agricultural production and population pressures has prompted an increased effort in environmental research (IDRC 1997). A significant step was the White Paper on Agenda 21 produced in 1994 which set out 78 programme areas, their objectives and funding support. This was a major achievement in integrated national planning for sustainable development. In 1999, investment in environmental protection and pollution control reached EUR 8.5 billion (about 1 % of GDP). Environmental technology, together with the scientific management of natural resources, has the potential to be a major growth sector in the knowledge economy.

In 1999, audits for cleaner production were carried out in many cities and provinces and substantial reductions were achieved in wastewater discharges (up to 40 %) and

gas emissions. A new project supported by the United Nations Environment Programme (UNEP) and the World Bank began in 1999 in the heavily polluted Taiyuan municipality in Shanxi. The aim is to provide 50 % of major firms with clean production systems by 2001.

Increased air pollution due to growth in the use of motor vehicles in cities has prompted the government to launch a 'Clean auto' action aimed at reducing emissions by measures such as extensive application of compressed natural gas for buses and taxis, improved combustion technology in new vehicles and extensive trials of electric vehicles. The first electric-vehicle charging network was established in Shanghai in 1999.

By extensive planting, China has increased its forested area to nearly 34 million ha, about 14 % of the country's area. This is only half of the world average of 27 %, and the per capita forested area is 0.12 ha or about one fifth of the world average. Major planting projects are in progress to reduce soil erosion and sand encroachment in the north-west and to reclaim the Yellow River delta.

China is still facing serious environmental problems; environmental pollution in many areas has not been checked and in some cases has worsened.

4.4.4. Space technology

A significant development in 1999 was the unveiling of a space vehicle to enable China to launch its own astronauts and conduct sophisticated experiments in space. China has been training astronauts in Russia for some years and on 21 and 22 November carried out a successful launch and recovery of an unmanned vehicle called *Shen Zou* (Divine or Magical Vessel). The vehicle made 14 earth orbits. Further test flights are planned with a manned flight within the next one to two years. A substantial technological achievement, the space vehicle is an expensive boost to Chinese prestige, and it remains to be seen whether significant advances in science can be achieved (*The Economist* 1999).

The launch confirmed the progress of the Chinese space industry which has continued to develop new launchers of the Long March family. Thus Long March I-D has been designed for launching smaller satellites up to 1000 kg in low earth orbit while Long March III-C and IV-B have been designed and used for launching satellites up to 3000 kg into geosynchronous orbit. For the space vehicle launch China used the new Long March II-F which is capable of putting a 10 tonne payload into low earth orbit. In 1999, China successfully launched a number of satellites for domestic purposes, for example meteorology and remote sensing, and the country has about a 10 % share of the international satellite launch market.

China's space programme has provided a valuable base for both civilian and defence industries.

4.5. International collaboration

In terms of international publications, China is ranked ninth in the world and needs to access the rest of the world's knowledge. International collaboration is one way of achieving this objective and China has established many international collaborative programmes with varying degrees of success.

In October, at a meeting of Asian and European science and technology ministers in Beijing, it was stated that China had established links with 152 countries and regions and joined 800 international academic organisations. The conference was organised under the auspices of the Asia–Europe Meeting (ASEM), which is a cooperative mechanism enhancing contacts between the two regions. One of the issues emphasised in the communiqué of the meeting was the importance of providing effective protection for intellectual property rights.

China has cooperated in R & D with the EU for about 17 years. In December 1998, the relationship entered a new phase with the signing of a formal agreement that gives China access to the fifth framework programme in areas such as biology, energy, aviation, space, telecommunications and agriculture. These are all critical areas for China.

4.6. Conclusion

In the August 1999 decision on technological innovation, the Chinese Government picked out the factors which according to a recent study (OECD 1999) lead to successful innovation. The keys to success are building an innovative culture, enhancing the skills base and technology diffusion, and promoting networking and clustering, as well as responding to globalisation.

There are deficiencies in all these areas in China at present and the challenge is to continue the reform process to build a technologically advanced country capable of competing in the global knowledge economy.

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