Science and Innovation Policy

KEY CHALLENGES AND OPPORTUNITIES
SCIENCE AND INNOVATION POLICY

Key Challenges and Opportunities

Meeting of the OECD Committee for Scientific and Technological Policy at Ministerial Level
29-30 January 2004

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
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Introduction

Science and technology (S&T) influence society as never before. Scientific achievements continue to push back the frontier of knowledge and increasingly contribute to the technological progress that affects how we live and work. New technologies help to protect the environment, to build safer homes, schools and factories, and to develop energy-saving transport systems. Advances in genetics save lives and improve health standards throughout the world. Information and communications technologies (ICT) have enhanced productivity in the advanced economies and made it possible for a greater number of individuals, firms and countries to take part in the knowledge-based economy. Continuing progress in biotechnology, nanotechnology and ICT, including broadband technologies, promises further improvements in living standards and economic performance. These scientific and technological advances are not without risks, however. Technologies that can be used to save lives and create jobs can potentially be used to harm populations and disrupt economies. Today, science and technology foment debates within society on issues ranging from genetically modified foods and nuclear energy to biometric identification.

Ensuring that science and technology continue to provide solutions to economic, health and environmental challenges while minimising potential risks requires OECD governments to improve the efficiency of public research and to facilitate the translation of research into commercial realities. They need to enhance incentives for business R&D, foster closer interaction between universities, government labs, firms and civil society, encourage the development of human resources in science and technology and address the interests of a more diversified set of stakeholders.
craft intellectual property rights (IPR) regimes that reward investments in innovation while encouraging the dissemination of scientific and technological knowledge. Such challenges will need to be addressed in a way that reflects the needs and interests of a growing number of stakeholders in government, academia, industry and civil society at large. This report draws on the results of the OECD’s work on science and technology to provide a basis for discussions at the Meeting of the Committee for Scientific and Technological Policy at Ministerial level on 29-30 January 2004.

**Public research systems face new challenges**

Governments play an important role in national innovation systems. Traditionally, their missions in funding and performing research have been to expand the pool of scientific knowledge for the benefit of society at large and to support R&D activities in areas where market mechanisms were inappropriate or insufficient to respond to social demands or meet specific government objectives. In OECD countries, fulfilment of these missions formed the basis of a social contract that bound science and society and provided the main rationale for public investment in scientific research, mainly in universities and government laboratories, but also stimulated business expenditure on R&D. In this context, governance of the public research enterprise was largely entrusted to governments and to the scientific community itself.

Over time, and especially in the last decade, science systems in most OECD countries have faced new challenges which go beyond the important and recurrent issue of ensuring the long-term sustainability of the research enterprise, notably as regards basic science. These challenges have called into question the prevailing social contract between science and society and pressed for reforms, or at least reconsideration, of the government's role in supporting research and of the governance of science systems. As a recent OECD publication indicates,¹ these challenges are broadly of two types: pressures for science systems to respond better to a more diverse set of stakeholders and the need to adapt to changes in the processes of knowl-
edge creation and transfer. These have seen a shift from an organisational model based on scientific disciplines to one that places a premium on multidisciplinarity, institutional networking and a blurring between curiosity-driven and problem-oriented research.

Responses to these challenges affect the decision-making processes that govern the setting of research priorities, the allocation of funds to the public and private research sectors and the management of research institutions. They must address efficiently the concerns of the diverse stakeholders in science and innovation systems. Greater attention needs to be given to various issues, most prominently the interface between science systems and industrial innovation, human resources for science, technology and innovation, and international S&T collaboration between and among developed and developing countries.

**Increasing pressures for public research to address economic and social needs**

The business sector and civil society in general have become more active stakeholders in the public research enterprise. Against a background of budgetary constraints and the rising costs of research, there has been greater pressure on public research to increase its contribution to innovation, economic performance and the fulfilment of social needs. The business sector and society at large are making legitimate demands for greater transparency and involvement in the setting of research priorities, and for more accountability in terms of the efficacy of public research investments. As a result, governments are led to develop more outcome-oriented approaches to the governance of science systems and the allocation of government research funding, but must continue to maintain a healthy and sustainable science base.

**Economic growth**

There is significant evidence, including some provided by the OECD,\(^2\) of the positive effects of public-sector R&D on growth and productivity and of the leverage effects of public research expenditures on those of the business sec-

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\(^2\) \text{OECD,} 

\text{Public research has had positive effects on growth...}
tor. Notwithstanding government’s declining share in total R&D expenditures in OECD countries, public research is expected to enhance its role in fostering innovation in knowledge-based economies (Figure 1). Indeed, as innovation becomes more science-intensive and firms increasingly acquire scientific and technical knowledge from external sources, businesses make more intensive use of public research. They increasingly fund it directly (Figure 2) and collaborate more with public research institutions. This results in a growing share of patents owned jointly by inventors from the public and private sectors. New patterns of industry-science relationships are further encouraged by the expansion of public/private partnerships programmes in many OECD countries.

**Figure 1. Public and private shares in total R&D funding, 1990-2001**

**Figure 2. Business funding of public R&D, 1990-2001, millions of 1995 USD PPPs**


…but society expects more targeted outcomes from public research.

While society at large reaps the benefits of innovation-led growth and, consequently, of the role that public research plays in that process, civil society’s demands are more targeted and reflect increasing pressures for public research to address specific and increasingly important
social needs such as better health, cleaner environments, and improved safety and security.

**Better health**

With ageing populations in most OECD countries and advances in life sciences that have increased the prospects of treating heretofore incurable diseases, health figures prominently among the areas in which society expects major improvements in well-being from R&D, particularly when it is performed in the public sector or through public funding. Trust in and emphasis on public-sector health research reflect a recognition that many of the most dramatic scientific advances in the life sciences have emanated from public research institutions and that the development of new therapies by the private sector, notably those based on biotechnologies, would hardly have been possible without it. The public is also increasingly aware that treatment for the so-called orphan diseases, for which industry lacks the necessary economic incentives, requires public research or strong government incentives for private-sector R&D. More generally, diseases related to the deterioration of the environment in developed countries and to pandemics in many developing ones are social problems that affect the health and well-being of populations. Finally, there is greater social demand for research-based regulations and testing protocols for the development and commercialisation of drugs or other products that can affect public health.

In response to the high social priority given to health, a number of OECD governments have increased R&D budgets for this sector or increased its share in total R&D budgets.\(^3\) Mounting health expenditures in OECD countries further motivate medical research aimed not only to develop new therapies but also to find more cost-effective ones. The share of total business research expenditures devoted to health-related research in the pharmaceutical and biotechnology industries has also grown significantly. In fact, after a period in which the potential returns to private R&D investment in health-related biotechnology were uncertain, public and private research now work jointly to respond to social priorities and to achieve mutual leveraging of public and private R&D expenditures in the health sector. Beyond this complementar-
ity, however, differences between public and private interests in health-related R&D remain. They have to do with the management of intellectual property rights (IPRs) in the biotechnology sector. In some instances – as in the case of inventions for which there is no technological substitute and whose protection can therefore block follow-on research – the scope of inventions protected by patents and the management of their property rights may hinder the diffusion of knowledge in the life sciences, although it is increasingly clear that patents, to the extent they are licensed, also provide an important vehicle for disseminating knowledge.

**Sustainable development**

Sustainable development is another area with strong social demand for greater public research. In its broadest sense, as now widely recognised, sustainable development encompasses interrelated economic, environmental and social issues which, for reasons of market or systemic failure, call for some kind of government intervention, in particular in the area of R&D. Sustainable development requires that resources be used in a much more efficient way and that new technologies emerge that radically alter the way human needs are met. Only rapid scientific and technological advances can meet this demand. Biotechnology, for example, is a significant driver of sustainable development. Sustainable development and innovation are thus interdependent.

The private sector lacks sufficient incentives to invest in R&D that would lead to innovations that could significantly curtail the long-term adverse effects of current production processes on the long-term availability of natural resources and thereby reduce economic and social costs to future generations. Similarly, the alleviation of environmental problems created in the process of economic growth often calls for the creation and diffusion of scientific knowledge of a multidisciplinary nature that the private sector has little incentive to develop – at least alone – and that the public sector can best promote.
Sustainable development is a global concern as developing countries grow more rapidly than OECD member countries. These countries still lack the capacity to generate the necessary knowledge and technology to make their growth sustainable. Much of the required knowledge and innovation can be developed through co-operation with OECD member countries in research and innovation. Also, global issues such as climate change and loss of biodiversity can only be addressed through international scientific and technological co-operation with non-member economies.

Civil society in OECD countries is increasingly aware that the issue of sustainable development goes well beyond protection of the environment. The public recognises that while economic incentives and regulatory measures may alleviate or solve the more visible environmental problems, notably through technological modifications undertaken by business, engaging economies on a path of sustainable development requires R&D efforts in which public research institutions, at national and global levels, should play a leading role. Given the complexity and the often multidisciplinary nature of the research problems involved, translating social pressure into the efficient organisation and funding of research is a difficult task that requires innovative approaches on the part of governments.

Enhanced security and safety

Finally, among the mounting social pressures on public research orientations, increasing concern for collective safety and security is not the least, whether for physical security against conventional weapons or weapons of mass destruction, travel and cargo transport security, bio-security against infectious diseases or cybersecurity. Three examples illustrate these concerns:

- The recent SARS epidemic demonstrated that the rapid diffusion of viral diseases associated with the increasing volume of international travel poses new threats to public safety. Restrictions on cross-border flows of people or quarantines imposed on affected...
persons are contingent, precautionary measures that do not get to the root of the problem. The public demands that governments, as caretakers of public safety, devote more research resources to protecting against this type of risk. While this risk is not in itself new, its magnitude and probability of occurrence have increased with the globalisation of human activities.

- In the aftermath of the traumatic shock of 11 September 2001, concerns about collective security issues have increased significantly in government, the business sector and society at large. There have been mounting fears that lethal weapons based on biological, chemical or nuclear technologies that can endanger the lives of large populations may fall into the hands of ill-intentioned individuals and groups that seek to destabilise democratic societies and their economies. It is also more widely recognised that more widespread and readily available conventional weapons can have devastating effects. Traditional measures for increasing security via controls and available technologies seem insufficient to address such threats and can have adverse effects on civil liberties. As collective security is a public goal, greater public and private research efforts are needed to develop new science-based technologies that can help detect and track potentially lethal biochemical products and fissile materials, facilitate the monitoring of transborder flows of people, or, like biometrics, improve the efficiency of identity checks at borders.

- The rapid spread of computer viruses, worms and other malicious code across the Internet has highlighted the vulnerability of public information and communications networks to hostile attacks. As society becomes increasingly dependent on such networks for a range of business, social and personal activities, cybersecurity concerns have mounted. The importance of data networks in providing a growing range of basic services – communications, energy distribution and financial transactions to name a
few – further highlights the importance of these concerns. The OECD has contributed to solving such problems, for example through revised security guidelines for networked systems that call for a stronger culture of security among users. However, further work is needed. There is a clear role for public and private-sector efforts to develop and deploy new technological solutions that can improve cybersecurity without unduly sacrificing ease of use and personal privacy.

Advice on science-based issues

As society increasingly influences priority setting and the management of public research and requires more accountability, it also demands that the public research sector continue to act as purveyor of independent scientific advice. While society at large reaps benefits from innovation-led growth and consequently from the role played by public research in that process, science-based technological advances can raise important ethical issues and questions about possibly adverse consequences for human life or the environment. Given the potential interest in rapid commercialisation of new products derived from such technological advances (notably in the areas of health, food and agriculture), civil society legitimately expects governments to pay greater attention to potential risks and the public research system to provide balanced, objective advice.

Responding to new challenges

While the importance of public science’s contributions to economic and social objectives has been recognised for decades, the context in which it operates has continued to evolve. The changes give renewed importance to certain fundamental elements of innovation systems which help science and technology to meet the challenges of economic growth, health, sustainable development, security and safety, and a host of others.

The public research system plays an important role in providing objective scientific advice on potential risks.

Today’s S&T policies are called upon to...
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... foster science-industry linkages, notably through more appropriate forms of governance of public research,...

... ensure that IPR regimes encourage investment in innovation,...

... promote the development and mobility of human resources in science and technology,...

- **Science-innovation interface.** Changing innovation processes and trends in the division of labour between the private and public sectors have brought out the need for strong industry-science linkages. Such linkages serve both to facilitate industry's uptake and commercialisation of public-sector research results (whether by existing firms or start-ups) and to ensure that research performed in the public sector is attuned to social and economic problems. Science-innovation linkages can take many forms, from contract and collaborative research and transfers of personnel to technology licences and the creation of spin-off firms. Government policies and regulations, especially those related to governance of public research organisations, have a significant influence on the effectiveness of these various channels.

- **Intellectual property rights.** Patenting has become more widely used to protect intellectual property and firms' competitive advantage. This trend has been reinforced by changes in patent regimes that have expanded patentability to new types of inventions and strengthened enforcement of patent rights. At the same time, the shift to more collaborative forms of innovation has stimulated the expansion of markets for technology through which technologies are licensed or shared. Public research organisations have also been encouraged by governments, if not required, to patent their inventions and attempt to license them to industry in order to promote their commercialisation. Ensuring that IPR regimes encourage investment in innovation while fostering the diffusion of scientific and technical knowledge and bolstering competition remains a continuing challenge for policy makers.

- **Human resources for science, technology and innovation.** Qualified scientists and engineers are the foundation of all scientific and technological endeavours in the public and private sectors. Increased demand for scientific advances and technological innovation continues to strain supplies of trained graduates, and
the rapid pace of technological innovation induces significant swings in industry demand for scientists and engineers, and for specific skills. More mobile human resources – between the public and private sectors, as well as internationally – are viewed as an important aspect of efforts to diffuse scientific and technological knowledge. However, their mobility can be impeded by labour regulations and practices in the public and private sectors. Policy makers are looking into a variety of measures to help increase graduation rates, mobility and the relevance of educational programmes.

- **International co-operation.** Issues of health, sustainable development, safety, security and economic performance are international by nature because they raise problems that span the globe and their solutions call for international co-operation. While scientific and technological research to address these problems often takes place within national R&D programmes, there are compelling reasons to forge international consensus and harness the diverse capabilities of many nations to reach solutions. The diffusion of publicly financed research results is an important step in facilitating international co-operation and improving the efficiency and effectiveness of the global scientific enterprise. Efforts to remove unnecessary barriers to such knowledge flows are an important step in addressing these and other issues.

These various issues lie at the heart of current debates about science, technology and innovation policy. Governments continue to wrestle with questions of how best to restructure and reform public research organisations to improve their contributions to social and economic problems without sacrificing the objectivity and independence of their advice and their ability to pursue curiosity-based research. Governments are also working with industry and civil society to improve the attractiveness of scientific and technological careers to students and to improve prospects for mobility. In bilateral and multilateral settings, they...
increasingly work with other governments and non-governmental organisations (NGOs) to foster international co-operation on issues of global concern. Each of these topics will be addressed in the context of the meeting of the OECD Committee for Scientific and Technological Policy at Ministerial level and will be further considered in the following pages.

Notes

3. In 2001 OECD governments spent more than USD 25 billion for health-related R&D. Between 1995 and 2001 health R&D appropriations increased on average by 9% every year in the OECD area. The US government remains the major contributor, accounting for three-quarters of total OECD health-related R&D expenditures. US appropriations have continued to grow faster than those in many countries. During this period, the National Institutes of Health (NIH) budget expanded by 15% annually.
4. In his classic 1945 treatise, Science: The Endless Frontier, Vannevar Bush argued for strong government support of basic science to stimulate economic performance, create jobs and contribute to improved health and national security.
The Interface between Science and Innovation

Science, innovation and economic performance

Innovation has become a key driver of sustainable economic growth and a necessary part of the response to many social needs. The determinants of innovative performance are also evolving, reflecting new patterns of knowledge creation, dissemination and appropriation. Science contributes more regularly and more directly to industrial innovation today than in the past, as reflected in the growing number of references in patent applications to scientific literature (Figure 3). The changing nature of scientific research makes earlier

Figure 3. Science linkage in G7 countries, for all patents, 1985-2002
Measured by the average number of scientific papers cited in US-issued patents

Source: CHI Research.
distinctions between basic and applied research less clear and less policy-relevant. In many fields, research is more interdisciplinary and curiosity-driven, and mission-oriented and profit-driven R&D are more interdependent. An effective interface between innovation and science systems is therefore more necessary than ever to reap broad economic and social benefits from public and private investments in research, to ensure the vitality and quality of the science system itself, and to improve public understanding and social acceptance of scientific and technological progress.

OECD work has identified developments in both the supply of and demand for knowledge that challenge established modes of governance and divisions of labour within the research enterprise. They call for more intense and flexible relationships between public and private research performers at regional, national and global levels, and they create new avenues for increased and more fruitful interaction.

Innovation occurs at the public-private and disciplinary boundaries

Many high-technology commercial successes and fundamental innovations with deep and positive social impacts had their roots in public research and came from findings that were impossible to foresee. Fundamental innovations such as the World Wide Web and the Web browser emerged, not from competitive market processes, but largely from government-funded defence research conducted in universities, industry and government laboratories. Important ICT innovations such as computer timesharing, inter-networking, computer work stations, graphical user interfaces, e-mail, parallel computing and relational databases all involved significant defence R&D on novel types of computing systems. Much of the R&D was conducted as part of government programmes, in some cases after the market had abandoned the research.

The role of publicly funded research in initiating new waves of revolutionary technologies, e.g. in ICT, biotechnology and nanotechnology, is likely to remain critical. Work in these and other socially important areas tends to be multidisciplinary, and innovation often requires mobilising the
complementary competencies of the public and private research sectors, e.g. through public/private partnerships (P/PPs). In general, time from academic research to industrial practice is shortening,1 and in some fields, academic and industrial research are converging. Much of the work in large industrial research laboratories and in small, high-technology start-ups is at the cutting edge of the search for new knowledge. For their part, university-based scientists may find themselves exploring the commercial applications of their discoveries almost as soon as they are made. A case in point is the branch of biology known as structural genomics, in which the academic and industrial communities have launched initiatives almost simultaneously.2

**Tapping outside sources of knowledge and exploiting intellectual property rights**

As innovation has become a more important source of competitive advantage and business investment in R&D and innovation has risen, innovative firms become increasingly dependent on external sources of knowledge rather than in-house research. Intensified competition, shorter product life cycles and expanded technological opportunities force them to innovate more quickly and focus their R&D expenditures, while seeking privileged and rapid access to complementary new knowledge in the public and private sectors. The result has been the emergence of a new organisation of industrial research, less centred on the individual firm, more based on networks and markets, and more reliant on small and medium-sized enterprises (SMEs) and new technology-based firms. Financial, regulatory and organisational changes have further boosted this technological outsourcing and promoted the development of technology markets for the exchange or sale of licences for patented technologies.

Public research organisations have become active partners in such arrangements. Limitations on core public financing and active efforts to promote the commercialisation of publicly funded research results have encouraged universities and other publicly funded research organisations to enter the growing market for technology (e.g. through patent-
Typically, contract research and spin-offs). While the bulk of industry-science relations will continue to take place through informal channels, the most spectacular change in industry-science relationships is the emergence of broad alliances between universities and firms and the accelerating development of formal, market-based relationships, especially the growing commercialisation of research results through spin-off companies and the licensing of intellectual property.

Intellectual property rights have become more important as high-technology patenting has expanded...

... and patent rights have broadened and strengthened.

Intellectual property rights become increasingly important in this context, as patents largely determine the reward to inventors and investors and the degree of diffusion of technology, including at the science-innovation interface. Firm strategies tend to place greater emphasis on patenting as a means of protecting their inventions and increasing their leverage in negotiations over alliances. More than 850,000 patent applications were filed in the US Patent and Trademark Office, the European Patent Office and the Japan Patent Office in 2002, against 600,000 in 1992. Most of this growth comes from new technology areas, notably biotechnology and ICT, where they are at the heart of business strategy. Around one-third of all patents currently filed are ICT-related, and ICT accounts for nearly half of the growth in patenting over the past decade. A surge in start-ups, many of them close to public research (e.g. spin-offs), has been instrumental in promoting technical change in biotechnology and ICT and was facilitated by extensive use of patents. Many of these companies have no assets other than their technology on which to rely to generate revenue. It has also permitted the expansion of markets for technology, as the increase in licensing contracts shows.

The strengthening and extension of patent rights over the past two decades have facilitated the boom in patenting and likely contributed to firms’ willingness to channel increasing amounts of capital to business R&D, the basis for expanding the knowledge-based economy. Major changes experienced by patent regimes include: i) extended coverage of intellectual property protection to software, genetics and business methods, with notable differences across countries; ii) increasingly flexible and less costly filing procedures, notably at the international level (European
Patent Office, Patent Convention Treaty); iii) new governing bodies, usually with more power to enforce rights (e.g. World Trade Organization, World Intellectual Property Organization); and iv) stronger and more frequent enforcement of patent holders’ rights in the courts, often as a result of newly created specialised courts for intellectual property. In addition, governments have used patent rights as a lever for adapting universities’ research agendas to the needs of society and facilitating the implementation of the resulting discoveries. Public research organisations are increasingly encouraged to patent and license their inventions in order to improve the diffusion of technology originating from publicly funded research.3

The expansion of patenting has also raised concerns, and its effects on innovation and performance are not fully understood. Issues that need to be addressed relate to strategic patenting, the quality of patents granted and research use of patented inventions.

- **Strategic patenting.** While growth in patenting is driven, in part, by increased inventive activity, it is also due to changes in business strategies. Strategic patenting can allow firms to increase their profits from commercialised inventions or unduly block competitors from entering related product markets. If taken too far, it limits the role of patenting in encouraging invention and diffusion of technology. Policy makers must protect vigilantly against detrimental practices and attempt to craft patent regimes that promote both innovation and knowledge diffusion. This requires insight into business patenting and licensing strategies and practices.

- **Ensuring patent quality.** Quality is essential to limit the potentially detrimental effects of patents on competition and knowledge diffusion. The growing number of patent applications received at patent offices makes it increasingly difficult to manage the patent system and ensure quality at reasonable cost. This has led to calls for greater commonality among

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Such changes have raised concerns about...

... unnecessary limitations on the use and diffusion of invention,...

... difficulties for ensuring patent quality,...
patent regimes and greater co-operation among patent offices. For newly patentable types of inventions such as genetic inventions, software and business methods, it is feared that some patents are excessively broad or protect inventions that are not new and innovative. In new technology areas, particular efforts are needed to help patent offices and courts build the experience and knowledge necessary to guarantee that patents granted are of high quality.

- **Research exemptions.** Researchers in the public sector are concerned about an apparent narrowing of the so-called research exemption, which allows them to use others’ inventions at little or no cost in the course of their research. A possible erosion of this exemption could have detrimental effects on public sector research in particular, and thwart efforts to increase its capacity to contribute to social and economic objectives. The legal status of the research exemption is not well defined in many countries and greater clarification is needed owing to the growth in university patenting and universities’ closer links with business. Information is also needed to determine how often public sector institutions or researchers actually use or invoke the research exemption.

Expanding markets for technology offer a means of diffusing patented technologies among a larger number of innovating organisations via licensing. They may improve the overall efficiency of business R&D by allowing firms to concentrate their R&D resources in their areas of relative strength and to rely on others for complementary technologies. By providing a channel for firms to sell or license technologies they cannot use themselves, they may also encourage firms to broaden their R&D portfolios and create business opportunities for firms specialised in matching technology supply and demand. The lack of research into the functioning of technology markets makes it difficult to fully evaluate the effects of stronger patents on innovation and economic performance and to determine how govern-
ments can further encourage and expand their use. Governments can encourage broad licensing of patented inventions by issuing guidelines in areas such as biotechnology, and they can explore ways to encourage alternative means of disseminating knowledge, such as encouraging the placing of inventions in the public domain.

Fostering the use and enforcement of patents has been the objective of patent policy in OECD countries over the past two decades, with a view to encouraging investments in innovation and enhancing the dissemination of knowledge. However, no systematic economic evaluation has been carried out to better inform policy choices. As patents play an increasingly central role in innovation processes in both the private and public sectors, patent policy must be subject to closer scrutiny by science and technology policy makers.

**Globalisation of scientific and innovation networks**

As the cost of innovation at the scientific frontier rises, countries need to be open to ideas from abroad. The challenge is greatest for small and medium-sized countries, but is also faced by larger ones. Focusing research on particular disciplines or problem areas in order to achieve critical mass and excellence can introduce new risks as innovations become more complex and advances in one field become essential to innovation in another (e.g. the symbiotic relationship between microelectronics, biotechnology and nanotechnology). More international linkages appear to be an effective way for small and medium-sized countries to obtain economies of scale and scope in their research enterprise.

Innovative activity tends to cluster in particular locations, often building on pre-existing infrastructure (e.g. a leading university, a key firm or an important public research facility). Globalisation and regional clustering of innovative activities are mutually enhancing, and some innovative clusters are major attractors of qualified labour and foreign direct investment. Harnessing national benefits from globalisation requires a regional approach to industry-science partnerships, since the nature of the international...
linkages to be developed depends on the characteristics of the innovative cluster. This is especially true for universities which, roughly speaking, can participate in three types of industry-science relationships: those involving multinational enterprises and world-class universities; those between universities and high-technology small firms; and regional partnerships between firms (often SMEs looking for shorter-term, problem-solving capabilities) and local universities.

The globalisation of industry has led to new forms of internationalisation. The interface between innovation and science systems was initially structured around national research organisations and domestic firms, at a time when the strategic interests of the different stakeholders converged easily towards national goals. International linkages were mainly created through the scientific community, which has a longstanding tradition of global networking. The situation evolved gradually over the 1970s and 1980s as government-sponsored international co-operation in technological development intensified, especially within Europe. The globalisation of firms’ R&D strategy and access to public research, together with the increased mobility of scarce highly qualified labour, now lead to much more fundamental changes.

More internationalised science-industry links can generate significant national benefits. In most countries the science-innovation interface remains the least internationalised part of the science and innovation system. This reduces its efficiency more than it helps ensure national benefits from globalisation. Governments have tended to be cautious with regard to foreign access to publicly funded R&D programmes, at times for reasons of national security but also for reasons of technological and economic competitiveness. Although foreign firms increasingly participate in public/private research partnerships in the OECD area, they do so on a small scale. Yet in a number of countries foreign firms make more intensive use of public research than domestic ones, and the efficiency of national measures is enhanced when recipients of government support are part of dynamic international networks. In addition, international policy commitments and pooling of public and private resources are often necessary to address common or world-scale issues, such as the environment or infectious diseases.
Enhancing the interface between science and industry

Many OECD countries lag behind in terms of modernising their science-innovation interface. Those that are forging ahead to build a more efficient and flexible interface face new challenges for reconciling the objectives of the science and industrial communities as they interact more closely.

Enhancing the synergy between science and innovation systems requires policies whose rationale and instruments fit the changing nature of innovation processes and meet the evolving needs of all stakeholders in public research. It calls for a comprehensive approach to reforms in a number of areas, including the governance of science systems, public/private partnerships in science-based innovation, management of IPRs and government incentives to business R&D. The OECD has assessed countries’ experiences in mobilising science for innovation and in promoting the quality of research results while ensuring that scientific fields of great economic and social importance receive sufficient attention. It has identified several domains in which many governments are reassessing policy and where emerging good practices could inspire current reforms.

Improving the contributions of public research organisations

Better governance of universities and public laboratories can be achieved through the use of new mechanisms for the steering and funding of research. These include greater use of project funding (typically contracts and grants awarded through competition) as opposed to institutional block grants, selective increases of funding for research fields that are linked to social and economic needs, and the creation of multidisciplinary research centres or networks that serve both to concentrate expertise in particular fields of science and technology and to foster research at the nexus of several disciplines. It also often requires a greater commitment to evaluating researchers and research organisations, as well as changes in the way such evaluations are conducted. Evaluation criteria must recognise that excellence in research and training of gradu-
ates has become, at least in some disciplines, more tied to industry applications and contributions to addressing social problems. They must take into account the quality of the research, its potential social and economic impact, and the value of university research in educating students. In this area, national initiatives are increasingly complemented by further efforts to develop benchmarking indicators and methodologies at international level and to use foreign expertise in national evaluation. The OECD can play a significant role in developing frameworks to guide such evaluations.

... without undermining their commitment to fundamental research or their objectivity.

The science system should not be made more responsive to identifiable opportunities at the expense of creativity and diversity in exploring the knowledge frontiers within a long time frame. Because changes in business R&D strategies generally strengthen longstanding disincentives for private industry to invest in fundamental research, the need for government support increases. Securing support for fundamental research is therefore a priority for most governments, even if some have found it difficult at times to meet this objective. It is also imperative to safeguard public knowledge in order to ensure the broad diffusion of the results of publicly funded research. Ethical guidelines are necessary to prevent or resolve conflicts of interest among public research institutions and researchers involved in collaboration with industry. Similarly, efforts must be made to ensure that the shift to more project-oriented funding does not undermine funding for the research infrastructure. Governments need either to develop strategies for including some fraction of the cost of new and updated research infrastructure in project funds or to establish separate funding sources for infrastructure.

**Exploiting multiple channels for science-innovation linkages**

Better management of IPRs in public organisations is essential in order to develop fruitful relationships between public research and industrial innovation. In nearly all OECD countries there has been a trend towards transferring ownership of publicly funded research results from the state (government) to the agent (public or private) that per-
forms the research. Countries differ in the allocation of ownership among performing agents (research institution or individual researcher), in licensing practices, in the allocation of resulting royalties and in provisions for ensuring that national benefits flow from patentable results of public research. A good practice seems to be to grant IPRs to the performing research organisation while ensuring that individual researchers or research teams share in the rewards.

Beyond better management of knowledge that is codified in patents and publications, efforts are needed to boost exchanges of tacit knowledge between the public and private sectors, through the movement of human resources, for example. Low rates of researcher mobility between the private and public sectors remain a major bottleneck to knowledge flows in many countries. There have been a number of initiatives in recent years to remove barriers and disincentives to mobility and flexibility in research employment with a view to stimulating flows of tacit knowledge between industry and the science system.

**Stimulating demand for science in the business sector**

Regulatory reform related to labour mobility, IPRs and licensing are often complemented by measures that stimulate business demand for scientific inputs and improve the ability of public research organisations to transfer knowledge and technology to the private sector. Spin-offs from publicly funded research make a significant direct contribution to innovation, especially in the information technology and, increasingly, the biotechnology/medical technologies sectors. Their indirect contribution to cultural change in public research organisation is even larger. Spin-off formation per dollar of public R&D expenditure is about three to four times higher in North America than in most other OECD countries. Government’s main role is to improve institutional frameworks (e.g. incubators, management of public research organisations) and incentive structures (e.g. regulations governing researchers’ mobility and entrepreneurship). Public seed capital to help finance early-stage investment, when uncertainty is high and the size of projects too small for private venture capital, has also...
proved useful, especially in countries where informal investors (business angels) cannot contribute much to filling the gap. There is also a case for public support and incentives to existing SMEs, especially in mature industries, to help them forge stronger links with the science sector.

Policies to enhance science-industry relationships must be part of an overall strategy addressing the business sector’s demand for the results of public research. Public research cannot be expected to compensate for problems in other parts of the economy, and reforms to public research organisations cannot, by themselves, generate market demand for science and technology. In many countries, rigidities in the public sector are compounded by the business sector’s lack of innovativeness. A business environment that is conducive to innovation depends on a wide range of policies that run the gamut of macroeconomic fundamentals, such as stable prices, to competition policies that are flexible enough to allow collaboration but firm enough to prevent collusion, and to microeconomic science and technology (e.g. public procurement and incentives to private R&D) and regulatory policies (e.g. IPRs). Many governments are rethinking ways to maximise national benefits from industry-science relationships involving industrial participants with a more global perspective. Building on globalisation to increase national benefits may require easier foreign access to national programmes and the relaxation of eligibility criteria regarding the location of publicly funded research activities. Additional efforts are needed to ensure coherence between regional efforts to develop innovative capacity and national and international programmes that aim to strengthen industry-science linkages.

Successful experience in promoting rapid advances in the science and technology that underlie industrial innovation in strategic fields suggests that relevant R&D programmes need to involve industry closely in their funding and management. Public/private partnerships for innovation promote co-operation between the public sector (government agencies or laboratories, universities) and the private sector in undertaking joint research projects or in building knowledge infrastructures. They fill gaps in the sci-
ence and innovation systems and increase the leverage of public support to business R&D through cost and risk sharing. Key challenges in the public sphere – delivery of health care, social services for ageing populations, sustainable transport, on-line security and privacy – offer promising opportunities to harness the creative capabilities of the private sector via public/private partnerships to achieve productivity gains and service improvements that can benefit society.

Notes

2. “Structural genomics” follows up the dramatic advances in DNA sequencing. It aims at determining the functions of the proteins whose composition is encoded by DNA. Doing so would lead to a quantum leap in the understanding of the integrated functions of organisms.
4. For example, the establishment of technology licensing offices, public/private partnerships in funding R&D, stimuli for co-operation with business and support to spin-off formation.
Fostering the Development and Mobility of Human Resources in Science and Technology

 Governments are increasingly aware of the need to address impending or future “shortages” of scientists and engineers. Meanwhile, in other OECD countries, especially those where business investment in R&D and innovation is weak, demand for scientific talent is constrained and this limits the ability of countries to reap the rewards from investments in human capital and may even generate a “brain drain” as young researchers emigrate abroad in search of opportunities. Addressing these issues and ensuring that the supply of people with science and engineering skills is sufficient to meet growing demand are of increasing importance to governments in OECD countries.

Innovation drives demand for scientific and technological talent

 By most measures, the population of human resources in science and technology is small relative to the general population, but it is a highly diverse group with a disproportionate impact on society and the economy. The OECD estimates that people educated in science and technology and employed in a job for which related skills are required represent 20% to 35% of the labour force in a number of OECD countries. In recent years, employment for such workers has grown more than for all other
occupational categories in manufacturing and services. These people work in a broad range of occupations: researchers, teachers, engineers, technicians, doctors, computer scientists, business managers, entrepreneurs. As such, they not only advance scientific knowledge and its diffusion in society but are instrumental in turning discoveries into innovations that create economic wealth.

Within this population, researchers – *i.e.* people working directly in R&D activities – are the backbone of the S&T workforce. The researcher workforce in OECD countries continues to expand, driven mainly by investments in R&D and innovation in the business sector. Between 1991 and 2000, the number of researchers in OECD countries rose from 2.4 million to 3.4 million, an increase of 42%. In 2000, about two-thirds of all researchers in OECD countries were employed by the business sector, although the share varies greatly: in the United States business absorbs four out of five researchers, but in the European Union only half. In Australia, more researchers are also employed in the public research sector than in business.

**Demand for public researchers is increasing in universities but less so in government labs**

Although business is driving overall demand for researchers, demand for researchers in the public sector, especially in universities, continued to expand in the United States, Finland and Ireland. In the United States, between 1991 and 2000, the number of researchers in the higher education sector grew by 34% while the number of government researchers dropped somewhat at the end of the 1990s. The European Union as a whole saw the higher education research population rise by 30% during the 1990s, while the government sector expanded by only 8%. In Japan the number of higher education researchers is also on the rise. While business is driving new demand for researchers, parallel investments in higher education R&D by governments, business and even private foundations are stimulating demand for researchers in universities.
Globalisation and competition are placing greater demands for flexibility in product and labour markets. As S&T personnel is a key component of R&D investment, it is not immune to these pressures. Large R&D-performing companies have downsized corporate labs and increased outsourcing. A growing share of business R&D spending and employment is found in small and medium-sized companies as well as in high-technology start-ups and spin-offs from universities. The services sector is also increasing its demand for S&T personnel. This externalisation of the demand for S&T personnel reflects the need by firms for flexibility in employment. It also places greater value on entrepreneurial skills among S&T workers.

Greater co-operation in research between business and universities is also having an impact on demand for researchers in the public research sector. Public research organisations increasingly rely on mobility of staff and the...
flexibility of temporary employment contracts to access expertise and respond to changing research priorities. These changes in public and private demand are putting pressure on education and training systems to adapt and enable young graduates to seek and find work in the new research environment.

The future supply of S&T graduates is at risk

Demand for S&T personnel, in particular, is expected to continue to grow in many OECD countries. The ageing of teaching faculty and researchers in universities and public research labs, notably in some European OECD countries and Japan, is expected to further increase demand for young researchers. In the medium term, however, waning interest in science among young people could hamper the ability of businesses and universities to meet demand. At the level of the EU, for example, it is estimated that meeting the goal set at the Barcelona Summit to raise R&D spending as a share of GDP to 3% by 2010 will require 700 000 new researchers.

The supply of human resources in S&T depends strongly, but not solely, on new entrants into higher education. Across the OECD, more people than ever are obtaining a tertiary-level education, which one-quarter of the population of the OECD area aged 25-64 has completed. The share reaches over one-third in the United States, Japan, Finland, Sweden and Ireland. OECD data show that university enrolments increased between 1995 and 2000, but, with a few exceptions, the increases were greater in countries with larger youth cohorts.

Not all countries are making equal progress in generating a sufficient supply of scientific and technological graduates despite the general upskilling of the population. Science and engineering graduates represent just over one-fifth of all graduates in OECD countries. In the EU in 2000, 26.4% of all university degrees were granted in science and engineering; the figure for Japan is slightly lower. In the United States, however, only 15.8% of
university degrees were in science and engineering. Recently, the number of graduates in science and engineering has increased in several smaller European countries (notably some of the Nordic countries). Larger economies in general have experienced slower growth or a drop in the share of science and engineering degrees in relation to total degrees.

Women represent a potential for increasing the supply of S&E graduates. However, while more women are university graduates than men, men outnumber women among science and engineering graduates, especially at the PhD level.

Foreign students, especially from Asia, contribute significantly to the supply of S&E graduates in several OECD countries: in the United States, a quarter of the stock of individuals holding PhDs in science and engineering are foreign-born. As a result of the economic downturn in OECD countries and the emergence of opportunities in sending countries, demand for foreign skilled workers and students has slowed. But there is also some evidence that a growing number of foreign students are seeking opportunities in Australia, Canada and the United Kingdom partly in response to perceptions of greater difficulty in obtaining student visas to the United States and as a result of competition for talent among OECD countries. This would suggest that the supply of foreign talent is responsive to changes or barriers in demand as well as to incentives from countries competing for talent. It would also seem to suggest that while foreign talent can bridge gaps in supply, it cannot be a permanent replacement for national investments in the S&T workforce.

**Improving labour markets for the S&T workforce**

The labour market is important because it affects the balance between the supply and demand for S&T graduates. For firms and public employers, which set the demand, a well functioning labour market is important for setting wages and meeting staffing requirements. For individuals, labour market conditions influence the field and duration of
studies. For higher education institutions, changes in supply or demand are important for signalling changes to higher education policies, including both access and curricula. When markets do not operate efficiently, e.g. when wages cannot adjust to an increase in demand and therefore stimulate supply, shortages or mismatches may arise.

The labour market for public sector researchers faces particular challenges. In many countries rigid and hierarchical employment policies in the public sector as well as poor salaries act as a barrier to the recruitment of young researchers. While tenure professorships remain an important means of rewarding and attracting graduates into teaching and research, there is growing recognition of the importance of other incentives too, such as performance pay systems, royalties from academic patenting, and possibilities for academic entrepreneurship and mobility.

Growing reliance on extramural funds and the decline in institutional funding are increasing the reliance of higher education institutions on temporary appointments. In many OECD countries there has been a decline in the share of full-time tenured faculty positions and an increase in non-faculty full-time contract positions such as post-doctorates. While post-doctoral positions are a way of gaining employment-relevant experience and establishing research networks, when they become excessively prolonged, there is a risk of creating an “insider-outsider” problem between established faculty and younger researchers. Career prospects, including employment conditions and salaries, must be attractive enough to encourage young people to pursue careers in teaching and public research.

Why mobility is important

Mobility of S&T personnel is an important channel for diffusing knowledge throughout the economy. From a labour market perspective, mobility is also important for the efficient allocation of labour across sectors. There is also some evidence that greater mobility of workers correlates with multi-factor productivity growth. Low mobility of S&T staff within and between sectors can make it more difficult to match demand and supply. Among
OECD countries, researcher mobility is higher in North America than in most EU countries and Japan, although the scope for fostering mobility differs in government labs and universities. The scientific discipline also matters. Overall mobility of S&T personnel is generally high but mainly flows from universities to industry and services and not in the opposite direction. However, while mobility is important, excessive mobility may have longer-term repercussions on demand for and supply of S&T personnel. High job turnover and frequent job changes involve transaction costs for firms and individuals and could reduce incentives for enterprise training and lifelong learning.

**Global competition for skills: pressures and opportunities**

There is a global dimension to the demand for highly skilled and S&T personnel (Figure 5). For one, access to international sources of S&T workers is becoming more important for meeting specific skill requirements. Second, foreign S&T workers contribute to research and innovation...

**Figure 5. Foreign and foreign-born workers in the highly skilled workforce**
Share of non-nationals in highly skilled employment, European countries, 2002

partly in response to demand as well as to globalisation, international mobility of students and highly skilled workers has increased over the past decade; the main flows have been from Asia to OECD countries and intra-EU. Previous OECD work has shown that foreign S&T workers make significant contributions to research and innovation in receiving countries. OECD countries are concerned about losing their competitive edge in what seems to be global competition for skills. In response, they are internationalising their higher education and research systems and facilitating the temporary immigration of qualified S&T professionals as a way to adjust more flexibly to demand shocks.

While economic factors play a role in decisions to migrate, factors such as strong support for research and an entrepreneurial climate of close co-operation between public research and industry are also important. Moreover, better research conditions and training and career opportunities not only attract foreign researchers but can also help enlarge the science base “at home” as well. OECD countries are investing in centres of excellence as a way to attract foreign graduates and researchers. Surveys indicate that much of the international migration of scientists and engineers is highly localised around knowledge-intensive clusters and in specific research areas.

Countries with an environment conducive to research, entrepreneurship and innovation are better placed to access the pool of foreign talent. While there is a risk of “brain drain” for sending countries, they can also benefit from returning emigrants who bring back new competencies, create new business ventures and build links to global research and innovation networks. Countries ranging from China and India to Ireland have shown that such return flows are contingent on building up domestic S&T capabilities to attract expatriate workers. OECD countries with internationalised higher education and research systems and an environment conducive to research, entrepreneurship and innovation are better placed to access the pool of foreign talent in science and technology. Countries would be short-sighted to rely too heavily in the longer term on importing qualified S&T personnel as demand conditions can change and sources of supply can shift. Sending countries, especially in Asia, are themselves creating opportunities for education and employment in science and technology. Related to this,
there is some evidence that these countries are not only attracting expatriates but also the outsourcing of high-skill jobs (e.g. in software and information technology).

Making S&T policies more responsive to changing demand

Science and technology policies have a role to play in the education and training of S&T personnel and deployment in the private and public sectors. Together with broader labour market and education policies, S&T policies can help address challenges such as shortages of science teachers or researchers and barriers to mobility. Framework conditions are also important in stimulating business investment in innovation and providing incentives for students to pursue education and careers in science and technology.

One of the most important challenges facing OECD countries is the waning interest in science among young people. However, no single policy measure can address the underlying causes, which may include unattractive or poorly adapted curricula, a lack of talented and well-trained teachers, the low status of scientists and engineers in society and social concerns about the effects of scientific and technological progress. Indeed, government, universities and business as well as individuals and society at large must play a role in shaping values and perceptions of science and technology. This section provides examples of recent policy measures to make S&T policies more responsive to changes in demand and skill requirements and to improve the contribution of S&T personnel to innovation and growth.

Raising public awareness and acceptance

Many OECD countries have launched programmes and initiatives to raise general scientific culture through science exhibits (e.g. science days, Web sites) or the establishment of new science centres or the renovation of science museums (e.g. natural history museums). In addition to such long-term measures, governments are increasingly engaging research institutions, firms, NGOs and scientists
in order to respond to social concerns about the risks inherent in technological progress by fostering public debate on scientific issues that touch upon moral, ethical, cultural or economic sensitivities. Scientific institutions (e.g. the National Aeronautics and Space Administration [NASA] in the United States) also reach out to the public and the media to make their missions clearer and increase awareness of their contributions to society and the economy.

**Enhancing the quality of scientific education**

The quality of teaching in science and mathematics plays an important role in students’ performance and hence in their further study and enjoyment of these subjects. There is some evidence that mathematics and science teachers with academic degrees in these fields produce students who perform better. There is also evidence that certified teachers outperform those that are not. Initiatives implemented in OECD countries include teaching certification reviews and special teaching programmes (e.g. IT literacy of teachers), often in partnership with industry, as well as measures to recruit PhDs for secondary teaching.

**Adapting higher education curricula**

Many OECD countries have made efforts to renew undergraduate curricula and reform PhD training to better suit changing needs, e.g. by shortening programmes and responding to growing demand for multidisciplinarity in scientific education in order to train researchers to work across scientific fields. As part of the Bologna Process, universities in the EU are moving to harmonise degrees up to doctorate level to improve recognition of diplomas, reduce drop out rates and foster mobility within and between member states. Furthermore, the greater focus on the commercialisation of research is leading to the development of joint degree programmes linking business and science, as well as efforts to enhance entrepreneurship and individual creativity. Breaking down traditional disciplinary barriers is no easy task, however, owing to institutional resistance and inertia. Often, higher education
institutions must rely on raising new money, including from industry, to develop multidisciplinary programmes (e.g. neuroinformatics). At the same time, universities must attempt to balance demands for multidisciplinarity with the continued need for specialisation.

**Attracting women and under-represented minorities into science education and careers**

OECD data show that there is still a gender gap in scientific education and that it is greater at higher degree levels. Women are also under-represented among working scientists and engineers. Closing this gap would help enlarge the pool of researchers for the public S&T sector and represents a major challenge for policy makers. Several OECD countries have made efforts to address this problem and to improve the representation of women and minorities among S&T graduates and researchers. Measures range from grants to support chairs for women at universities (NSERC awards in Canada) to preferential policies towards equally qualified women candidates (e.g. Sweden, Finland). However, recent research suggests that efforts to close the gender gap in science must begin at the earliest levels of schooling. On the employment side, equal opportunity policies, flexible working hours and parental leave are also important for encouraging women to pursue research careers in both the public research and business sectors.

**Funding and training of new PhDs and post-doctorates**

To increase the number of PhDs, several OECD countries have measures focused on improving PhD training by giving graduates more autonomy while providing more mentorship and funding. Most graduate funding comes in the form of fellowships funded through institutional (core) and agency funding or grants. Countries are increasing the number and amount of fellowships. Universities are also partnering with industry to train PhDs and post-doctorates (e.g. in France and the United Kingdom) in order to improve the match between researcher skills and industry demands. One of the lessons from OECD countries that have succeeded in increasing the...
supply of S&T graduates is that policies should focus on the entire supply pipeline, from primary and secondary schooling to university education and PhD training, and should involve industry to leverage competencies and resources.

**Fostering the mobility of researchers**

Regulations on dual employment or restrictions on participation in entrepreneurial activities are being removed in many OECD countries, thereby helping to create incentives to move between public research and business. Reforms to encourage decentralisation and greater autonomy for universities facilitate mobility by giving universities greater control over the management of human resources. Competition for research funds can also indirectly stimulate the mobility of researchers, as they will follow allocations. Fostering mobility, however, is a question both of removing regulatory barriers and of creating incentives. Human resource management policies in businesses and public research institutions that reward mobility as part of career advancement are important. OECD countries have launched mobility schemes to improve national and international flows of researchers (e.g. EU mobility schemes). To ensure that these benefits are translated into overall labour mobility will require complementary efforts to harmonise qualifications systems. While mobility schemes targeted to young researchers help expose them to different environments, mobility for mid-career scientists and faculty remains a greater challenge.

**Stimulating public and private demand for S&T workers**

Framework conditions in the business sector play an important role in matching supply and demand and helping workers adapt to technology-induced changes. They also affect incentives for firms to invest in R&D and hence to recruit highly skilled personnel as well as incentives for students to pursue scientific studies. Without business conditions that facilitate the creation of business start-ups, the demand for, and the contributions of, S&T personnel may be limited. At a general level, these conditions include effective venture capital markets,
regulations that facilitate firm entry and exit, and, more broadly, a business climate that rewards risk. At the firm level, they include management policies that provide competitive salaries and opportunities for researchers to pursue careers in senior management and that reward mobility.

In the public sector, changes in the governance of research systems can also strengthen the contributions of S&T personnel. In many countries the responsibility for public-sector research pay scales and working conditions has shifted from national governments (which may set framework conditions) to institutions and local social partners. Some countries are also experimenting with performance-pay systems for university researchers to make salaries of researchers more flexible.

**Improving statistical information on human resources in science and technology**

Our understanding of human resources in science and technology is imperfect owing to insufficient or inadequate statistical information. Gaining a better understanding of S&T human resource requirements is crucial for planning education and research training policies. Assessing whether declines have resulted in shortages in the academic and R&D labour markets requires, at the very least, data on the wages as well as employment/unemployment patterns of such graduates. More could be done to exploit existing data, such as censuses, labour force surveys, population registers and industrial occupation data sets, as a way to monitor trends in the demand for HRST. Extending the coverage of R&D surveys is another way to include more demographic information on human resources. Until recently, OECD data on researchers was collected on a full-time equivalent basis. This precluded a breakdown by gender, age or nationality. Better coverage of recent S&T graduates is needed to measure trends and inform policy making about the career paths of graduates.
Notes

2. The United States’ National Science Foundation estimates that between 2000 and 2010, employment in science and engineering occupations will increase three times faster than the rate for all occupations.
3. See *Innovative People: Mobility of the Highly Skilled* (OECD, 2001); *The New Economy: Beyond the Hype* (OECD, 2002).
Global Opportunities and Challenges

Worldwide scientific co-operation has a long and productive history. Today, a number of factors make such co-operation even more desirable. They include:

- The growing importance of understanding global phenomena.
- The increasing dispersion of expertise, resources and information among OECD countries and their concentration within the OECD area.
- The increasing international mobility of scientists and the greater ease, owing to ICT, with which they can exchange information and organise transnational research networks.

Opportunities for co-operative international research abound in all areas of social concern (e.g. health, environmental protection, economic development, safety and security) and across the full spectrum of scientific domains (e.g. physical sciences, life sciences, Earth sciences, social and behavioural sciences). However, international co-operation among OECD countries, and between them and the developing world, is not an end in itself. Its advantages include the stimulation and synergy that international networking can make possible; efficiency gains through the sharing of financial resources, information and facilities; and cultural input at both the scientific and the personal level. Co-operation with developing countries can help build research capacity by providing access to world-class training and knowledge and thus help to stem the “brain drain”. On the other hand, countries and scientists must weigh the loss of some control and “home team advantage”, added administrative complexity, the need to modify or adjust national priorities, funding plans and schedules, and the potential...
difficulties involved in working abroad for scientists (and their families). The importance of these factors varies from project to project and the views of practising scientists may be different from those of their sponsoring governments.

In assessing the prospects for a specific new international research project, it is, of course, necessary to take account of the scientific and social needs and the expected benefits. However, experience has shown that it is often important to address science policy issues, i.e. to optimise the conditions under which the research is proposed, reviewed, conducted, managed and financed. This is especially important when long-term, large-scale projects such as those involving the creation of large infrastructures are contemplated. Small-scale international collaborations involving the exchange of one or two researchers and/or equipment and data can often be arranged as needed by individual scientists or their institutions. Medium and large-scale multinational projects, however, must often involve officials from funding agencies and other governmental institutions, who must analyse and weigh the likely benefits, costs and modalities of potential collaborative projects before they are undertaken. Accordingly, there is a need for venues where multilateral policy-level consultations can take place among scientists and officials at the request of the potential partners. The OECD provides one such venue.¹

Prospects for international collaboration for future accelerator-based facilities in high-energy physics

High-energy physics (HEP) has traditionally been characterised by, and benefited from, international collaboration, including international exchanges of personnel, ideas and equipment. For the most part, however, major accelerator facilities have been conceived, funded and built on a national basis (or, in the notable case of the European Organisation for Nuclear Research [CERN], as a regional collaboration). The future vitality of HEP will depend on strong national programmes, and there will be a continuing role for national and regional facilities. However, as regards the largest, most advanced accelerator-based facilities, the field is entering a new phase, where the needed financial and intel-
lectual resources will exceed those available on a national, and even a regional, scale.

A case in point is the highest-priority big project identified by the scientific community: a linear electron-positron collider (LC). This is an extremely difficult and ambitious project, the successful exploitation of which promises to deliver major advances in exploring the realm of physics beyond the Standard Model of Particles and Fields. In three geographical areas (Europe, Asia and North America), scientific communities have called upon their governments to host a global-scale international collider collaboration within a timeframe that will allow for overlap with the Large Hadron Collider (LHC) proton-proton collider now being constructed at CERN and due to begin operation in 2007. Although many technological problems associated with the LC have already been resolved, much work remains to be done before a final design can be agreed upon. Some of the important challenges confront policy makers rather than scientists or engineers. It is not clear at this time how to reach a consensus on the site of the linear collider or how the financial resources can be mustered. World-scale collaboration will require negotiations on the managerial, administrative and financial aspects of the project. Accordingly, governments will have to develop new institutional and organisational frameworks for the LC and other future global HEP collaborations. This will require the harmonisation of existing national and regional procedures within which big, complex and expensive projects are developed and operated. The scientific and policy aspects of ensuring an internationally co-ordinated, productive future for accelerator-based HEP have been examined by a group of physicists, laboratory administrators and funding agency officials. They are presenting their findings and conclusions for consideration by interested governments.

Fostering international co-operation in the emerging field of neuroinformatics

Understanding the human brain is a crucial scientific challenge for the 21st century. This intellectually fascinating task is made urgent by its practical applications, since advances in the field will lead to breakthroughs in the pre-
... but researchers need to process enormous amounts of data...

Neuroscientists, having developed elaborate methods for investigating the brain in fine detail, now face the challenge of managing the enormous amounts of raw data and the many useful inferences drawn from them. The amount of data is huge, given that the brain itself is responsible for controlling all patterns of behaviour, thoughts, perceptions, memories and emotions from within its 1.5-litre package of 100 billion nerve cells, 3.2 million miles of nerve fibres and its million billion neural interconnections. The data are also enormously diverse. Their source may be chemical, biophysical, structural, morphological, physiological or behavioural, with each domain generating data with their own characteristic parameters. Data are being gathered at all levels of biological organisation, from the genetic, cellular and neural network levels up to whole-brain structure and function. Brain measurements produce data on processes as disparate as genetic regulation, cellular development and plasticity, signalling in neural circuits and cognitive functions. The time scales are highly variable as well, from microseconds to days or even years, and they interact with other processes and play out against the background of overall nervous system development, which takes place over an individual’s entire lifetime.

... and neuroinformatics would benefit from international co-ordination.

Like other scientific domains (e.g. genetics, astronomy, Earth sciences), neuroscience has reached a point where the data-intensive nature of the work and the complexity of the research subject naturally led to the creation of a new field, neuroinformatics, which stands at the intersection of neuroscience and information science. The principal aims of this field are: i) to optimise the accumulation, storage and sharing of vast amounts of primary data and of large, structured neuroscience databases; ii) to develop tools for manipulating and managing the data; and iii) to create computational models of brain structure and function that can be validated using the data. Naturally, the development of a new field requires establishing its identity, creating an organisa-
International access to publicly funded research data

International collaboration among scientists has always led to the sharing of research data, but this was traditionally restricted to well-connected networks of scientists, well-identified research subjects and certain scientific communities. If one did not belong to such networks or communities it was difficult to know about existing data or, if they were known, to access them. Modern ICTs have changed this. Digitalisation makes it possible to collect and process more data, make them readily accessible and distribute them via the Internet, and put them to multiple uses by providing them in standardised databases.

Whether or not publicly funded research data should be made openly available as much as possible is the object of widespread discussion within the international community. Many stakeholders believe that this will advance science, enable researchers to improve the quality of research results as well as the quality of researcher training, and lead to economic and social benefits. On the other hand, it is accepted that national legislation with regard to privacy, trade secrets, copyright or national security often limits open access to research data.

Research data are now often shared quite extensively within established networks by using both the latest technology and innovative management techniques. However, this is not standard procedure in all fields of science. In addition, there are a number of important barriers to making data openly accessible and sharing them efficiently. First, in most cases, it is up to individual researchers to...
decide which data they want to disclose. Second, if data are collected in large centralised databases, collection and processing are often not standardised, and use for other than the original purpose is difficult. Third, costs of managing large data collections may also prevent them from being accessible to a larger public.

Successful arrangements for data access and data sharing have a number of key attributes and operating principles. They include transparency of data access and active data dissemination, methods to assign and assume formal responsibility for data management, methods for controlling the quality of data, interoperability between different databases, rules to ensure respect for privacy, intellectual property rights and other legal or ethical matters, and provisions for the financing of data access and data sharing. It may therefore be useful to establish international guidelines and principles for such arrangements by addressing the above issues. Such guidelines would have to be based on careful studies of the advantages and limitations of open access to publicly funded research as well as of the financial implications, and should take account of the requirements of both OECD and developing countries.

The OECD might provide an appropriate forum for discussions. The OECD has some experience in establishing similar guidelines for other fields of digital data handling, and could therefore provide an appropriate forum to examine options for guidelines and principles on access to digital research data obtained with public funding, which could be adopted by the OECD Council as a basis for action by governments in OECD countries.

Enhancing sustainability through international S&T co-operation and bio-based technologies

Climate change, loss of biodiversity, poverty and lingering inequity are among the most significant challenges to achieving the goal of sustainable development of the global economy. Successfully meeting these challenges and ensuring sustainable economic growth will require progress across a broad range of policy areas. There is clear and growing recognition that science and technology can and
should play a key role in achieving this goal. In addition to facilitating access to and use of new technologies, research and innovation can lead to ways to utilise resources more efficiently to create wealth and enhance welfare.

Global challenges require global responses. While the capacity to create and diffuse the needed knowledge is mainly found in OECD member countries, the knowledge and technologies arising from such research will be needed in non-member economies as well. International co-operation will be necessary to realise science and technology's full potential to enhance global sustainability.

As expressed at the World Summit on Sustainable Development (WSSD) in September 2002, and more recently at the 2003 G8 Summit meeting in Evian, sustainable development needs to be promoted through application of science and technology by strengthening national innovation policies and enhancing existing global collaborative networks. Co-operation should extend from governments to business and civil society. International co-operation and partnership in research and knowledge transfer will help build non-member economies' capacity to harness science and technology as a means to achieving sustainability. The OECD can provide a forum for discussing policies to enhance such partnerships.

New technologies that offer opportunities to decouple economic growth from environmental degradation are becoming available. For example, genomics and pathway engineering are delivering new generations of enzymes and other bio-transformation technologies that open up the potential for using renewable biomass as feed-stocks for industrial products and processes across an increasing range of economic sectors, both “traditional” and “novel”. It is difficult to estimate with any accuracy the likely added value realisable by widespread adoption of these industrial biotechnologies (or “white” biotechnology as they have been termed in Europe), but it could be very significant both in economic and environmental terms if uptake rates are favourable. A recent OECD report shows that successful applications of eco-efficient bio-transformations...
exist and are in use in a range of countries and industries today.

Such bio-based technologies can and will contribute to the goal of sustainability. They will make it possible to develop innovative products and services with improved economic and environmental performance that draw on renewable resources and biological processes to meet the needs of society. They have the potential to pervade and transform economies, affecting the health, food and agriculture, industrial manufacturing and energy supply sectors, and, by increasingly interacting with information technology, they can open up new areas for economic development and growth.

However, the rate of uptake of these and other technologies – and their subsequent impact on sustainability – will be affected by the choices made by governments, industries and society. International efforts will be necessary to develop a clear vision for moving towards a bio-based economy and the sustainability gains it promises.

**Biological resource centres**

A vision for moving towards more bio-based technologies would need to address how to establish an international S&T infrastructure to facilitate access to the biological materials (living organisms, cells and genes) and related information – together referred to as “biological resources” – that are the essential raw materials for the advancement of research based on the life sciences.

Many biological resources are held in *ex situ* collections, some exclusively. Such collections are fundamental to harnessing the world’s biodiversity and genetic heritage for the benefit of humanity. They also form part of the critical infrastructure supporting biotechnology, bio-processing and the development of new approaches to diagnosis and prevention of disease. They also play a small but vital role in ensuring the safe, regulated use of organisms that are pathogens for humans, plants or animals.
As the complexity and diversity of life science research escalates, there is increasing demand for rapid and reliable access to high-quality biological resources. Collections must achieve the standards of quality and expertise demanded by the international community. At present, however, many repositories may not meet these expectations as access to biological resources is often difficult and repositories may be duplicating the work of others, which is increasingly expensive. Even if duplication is avoided, adequate funding is required in order to meet expected standards and assure sustainability. Because it is difficult for any single entity to supply the full financial support necessary, international co-operation is needed.

OECD member countries addressed these issues in a report\(^6\) that envisaged the agreement of common standards for *ex situ* maintenance of biological resources and for interoperability of the information systems that support them. Collections that meet these standards should be brought together in a high-quality network distributed across the globe to allow for easy access to biological resources and data and help avoid the need for duplication within or between countries. Such a global network would need to include collections in both non-member and member countries.

If a move towards a bio-based economy is to be successful – and not only in OECD member countries – such a network will have to be established to ensure the world’s scientific community access to the materials and information they need.
Notes

1. The topics presented in this section were addressed, at the request of member governments, by the CSTP and/or its working parties. They span a wide range of scientific domains (from biology to fundamental physics) and subject areas (from concrete collaborative projects to general policy guidance). They represent only a fraction, however, of the science-related issues that have been discussed at the OECD in recent years.

2. The Human Genome Project is a good example of a large research endeavour in which an openly accessible data repository was used successfully by many different researchers throughout the world for different purposes at different places and times.

3. Based on case studies of the following institutions: European Organisation for Nuclear Research (CERN), European Bioinformatics Institute (EBI), functional Magnetic Resonance Imaging Data Center (fMRIDC) and the Global Biodiversity Information Facility (GBIF). These case studies have been published as “Promise and Practice in Data Sharing” by the Netherlands Institute of Scientific Information Services and are available through its Web site.


5. The Application of Biotechnology to Industrial Sustainability (OECD, 2001).

MEETING OF THE OECD COMMITTEE FOR SCIENTIFIC AND TECHNOLOGICAL POLICY AT MINISTERIAL LEVEL
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Science and Innovation Policy

KEY CHALLENGES AND OPPORTUNITIES