Committee on Scientific Planning and Review Report

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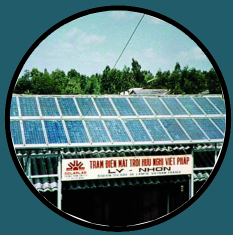

Identification of Key Emerging Issues in Science and Society: an International Perspective on National Foresight Studies

ICSU

The International Council for Science (ICSU) is a non- governmental organisation representing the international science community. The membership includes both national science academies (98 members) and international scientific unions (26 members). The combined expertise from these two groups of scientific organisations provides a wide spectrum of scientific expertise enabling ICSU to address major international, interdisciplinary issues, beyond the scope of the individual organisations. ICSU builds upon this scientific expertise in a number of ways. It initiates, designs and co-ordinates major international, interdisciplinary research programmes, particularly in the areas of global environmental change. It also establishes policy and advisory committees to address important matters of common concern to scientists, such as education and capacity building in science, access to data, or science in developing countries. ICSU acts as a focus for the exchange of ideas, communication of scientific information and development of scientific standards and networks. Because ICSU is in contact with hundreds of thousands of scientists worldwide, it is often called upon to represent the world scientific community.

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Identification of Key Emerging Issues in Science and Society: an International Perspective on National Foresight Studies

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Foreword

Scenes surrounding international science are changing rapidly. Societal problems are increasingly requiring inputs from science, and their complexity demands stronger collaborating efforts of the international scientific community beyond disciplines. The conduct of science is also increasingly affected and driven by economic and other societal concerns: Thus it is necessary for the scientific community to be conscious of emerging concerns of societies. ICSU has a mission to mobilise the resources and knowledge of the scientific community responding to these emerging scientific and societal concerns in a timely manner. The Committee on Scientific Planning and Review (CSPR) was created to identify scientific priorities and develop proposals for new scientific initiatives of ICSU.

The CSPR believes that the process for identification of ICSU's priorities should be built on ICSU's original strength as a "bottom up" organisation through an iterative process involving the entire ICSU constituency. This consultation process is essential, as the priority issues to be identified must be generated and "owned" by the members of the ICSU family.

Earlier in this process, the ICSU Union Members were solicited for inputs on their emerging issues on the occasion of the Unions Meeting in February 2001. The CSPR also recognised a need to identify emerging scientific issues in national contexts. Being aware of the existence of national S&T foresight as systematic efforts to identify emerging S&T issues for a country with a medium-long term aspect, it decided to commission an analysis of results from existing "foresight" exercises. After a competitive tender, SPRU (Science and Technology Policy Research, University of Sussex) was chosen as a contractor. ICSU National Members were invited to contribute to this study by providing relevant information from their countries.

Based on a meta-analysis of scientific priority areas identified in selected national and regional foresights, this report provides us with information on national and regional concerns, in particular those which deemed relevant to ICSU's mission. However, we are well conscious of the limitations of this study due to the nature of "foresight" as a methodology. Results are not necessarily the same as those that might be identified by the scientific community itself, as these national exercises normally reflect more strongly the socio-economic needs of society where science and technology may make a contribution.

The information provided in this report will hopefully be found useful and stimulate discussions within the ICSU family at and after the ICSU General Assembly in September 2002. In considering ICSU's priorities, we also need to take due account of discussions taking place outside of ICSU on a wide range of issues of emerging concern to the global community. By doing so and along with additional inputs from the ICSU family, I am hoping that ICSU can incorporate new developments in science and society into its future agenda.

Lastly, I would like to stress that we have just started our dialogue process within the ICSU family towards the identification of ICSU's new initiatives. Based on the discussions at the General Assembly, ICSU Union and National Members as well as Interdisciplinary Bodies will be asked to provide further inputs. The CSPR expects to present a report on priority issues where involvement of ICSU would be timely and necessary in mid-2003.

Professor THOMAS ROSSWALL

Executive Director
ICSU

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Acknowledgements

This study would not have been possible without the help and contributions of a large number of individuals and institutions. The authors are grateful to the member organisations of ICSU around the world who helped identify and supply material or who suggested others to be approached. Likewise, there are numerous SPRU contacts who provided much helpful information and advice. The authors would also like to thank all those individuals and institutions who supplied the material on Foresight exercises that formed the basis for this study. An especial word of thanks is due to the ICSU Steering Group for the project (Professor Winfried Blum, Dr John Marks and Sir Dai Rees) who, along with Sachiko Ishizaka at ICSU, contributed so much to the project by way of ideas, advice and comments. Several useful suggestions were also made by members of the ICSU Committee on Scientific Planning and Review (CSPR).

Executive Summary

1. The aim of this study has been to assemble and analyse information in order to help the International Council for Science (ICSU) to develop an agenda of selected major scientific issues for it to address in coming years. Sponsored by ICSU, the study was carried out by SPRU (Science and Technology Policy Research) between January and June 2002.

2. The study was based on an extensive review of recent national and international science and technology 'Foresight' exercises conducted by governments, national academies, other public bodies and international organisations in over 20 industrialised, transition and developing countries. The conclusions therefore reflect the nature of this starting material and the countries covered.

3. The study has analysed and synthesised the results of those exercises. Using various selection criteria agreed with the ICSU Steering Group, we have identified specific areas where scientific developments could have a significant impact on the future of science, technology, the economy and society over coming years.

4. Particular emphasis has been given to research areas where there is likely to be a major scientific advance over the next five to ten years and perhaps a positive impact on other scientific fields, where the research requires collaboration across countries and across disciplines, where there are likely to be major benefits to society but may also be associated ethical issues to address, and where developing countries have certain advantages and/or may see important capacity-building opportunities.

5. A medium-length list of 28 scientific areas that meet these criteria has been drawn up, discussed with the ICSU Steering Group and refined (see Table 3). These 28 areas have been clustered under six main headings – (i) life sciences and biotechnology, (ii) human health, (iii) environment and sustainable use of natural resources, (iv) energy, (v) information and communications technologies, and (vi) materials science.

6. The similarities between the various Foresight exercises tend to be greater than the differences. Correspondence analysis shows that the majority of the scientific areas suggested for selection (in Table 3) are considered fairly equally by developing and industrialised countries in their Foresight exercises. This is particularly true for the scientific developments in the biological, energy and environment fields.

7. However, there are some differences in the general nature of the Foresight priorities identified between developing/transitional economies and industrialised nations. The former tend to focus more on technological areas as well as on developments needed to solve their more immediate problems, and they place less emphasis on more basic scientific areas and the 'hard sciences' (although the latter may be indirectly involved in many of the Foresight areas). Conversely, industrialised countries place more emphasis on scientific developments in materials science, information and communication technologies, and human health sciences.

8. The category of environment and sustainable use of natural resources accounts for the largest number of scientific areas that best meet the selection criteria with 12 areas, followed by life sciences and biotechnology with seven, while there are far fewer related to the physical sciences. Possible factors accounting for this include a fundamental shift at the end of the 20th Century from physical to life and environmental sciences, a shift in the 'social contract' between science and society, and the specific selection criteria used in this ICSU study.

9. Scientific areas that have been identified in a large number of Foresight exercises include the genetic modification

(GM) of food or crops, new/renewable clean energy sources, human genetics and functional genomics, 'other biotechnology' (e.g. production of antibiotics or enzymes using micro-organisms, and 'gene machines' to make new proteins), telecare, biodiversity, water recycling, and water-use saving/efficiency technologies.

10. The scientific areas that appear to meet all the selection criteria employed here include the genetic modification of food or crops, pest control methods (including biopesticides), biopharming (using natural products and their active ingredients for pharmaceuticals), intellectual property, medical and supportive technologies (e.g. for the elderly and disabled), biodiversity (including bio-mapping, databases on biodiversity, and conservation), and risk and disasters.

11. It is intended that the medium-length list of scientific areas arrived at in Table 3, together with the preliminary assessments of each in terms of the agreed selection criteria, provide useful information for stimulating discussions among ICSU members and at the ICSU General Assembly in September 2002 with a view to determining what initiative(s) or other action might be taken by ICSU.

1. Introduction

1.1 Aims

The overall objective of this study is to assemble and analyse information in order to help the International Council for Science (ICSU) to develop an agenda of major scientific issues that it is committed to addressing in coming years. More specifically, the aim has been to identify a number of key emerging developments in science and society that require international and cross-disciplinary collaboration of the global scientific community – developments where ICSU might take the initiative in promoting such scientific collaboration and which are likely to result in substantial benefits to society.

Science and technology Foresight offers a potentially fruitful approach for helping ICSU to address its mission "to mobilise the resources and knowledge of the international scientific community from all disciplines on problems of importance to society and to science". Under the new Statutes of 1998, one of ICSU's priorities is "to identify and develop a scientific agenda on scientific and societal issues requiring global cooperation across disciplines". ICSU, given its wide-ranging membership, needs to develop further its intellectual capability to recognise at an early stage important developments in science that are likely to have a major impact on society. Such an 'early warning system' can then enable scientific efforts around the world to be directed more promptly and effectively.

To achieve this requires a mechanism for identifying emerging scientific questions for the global scientific community where ICSU can develop and co-ordinate its scientific agenda. We start from the recommendation of ICSU's Committee on Scientific Planning and Review (CSPR) to draw upon the Foresight efforts of national bodies rather than embarking on a fresh process *ab initio*. Not only is this more cost effective but it also enables one to take into account the wide range of perspectives of transition and developing economies and well as industrialised nations, and the issues that emerge from the Foresight process of dialogue between researchers, funders and the 'users' of research results. It should be noted that the scientific priorities that emerge from Foresight exercises are therefore not necessarily the same as those that might be identified by scientists consulting among themselves (i.e. without government and users being involved in the process). The latter process might generate a list of priority scientific areas, whereas the priorities identified in Foresight exercises tend also to reflect the 'needs' of society (economic, social, environmental, cultural or whatever) where science and technology may make a contribution.

The study is based on an analysis of recent science and technology Foresight exercises carried out by governments, academies, other public sector bodies and international organisations since 1995. The survey includes national Foresight exercises as well as some involving international collaboration. It covers Foresight initiatives in industrialised nations, transition economies and developing countries.

From this material, we have attempted to identify emerging scientific areas that seem to be particularly relevant to ICSU's mission. This has entailed developing and agreeing with the ICSU Steering Group for the project a number of selection criteria to apply to the long list of potential scientific and technological developments identified in the various Foresight exercises. Those criteria have been used to produce a medium-length list of scientific developments that appear to be most pertinent to ICSU's mission. Suggestions as to key emerging issues in science and society on which ICSU might focus its attention are set out later in this report.

The SPRU study thus forms part of an initiative by ICSU to launch a more systematic effort to select emerging scientific areas on which ICSU should focus in formulating its scientific agenda. The SPRU study is an early step in a wider, longer process rather than an end-point in itself. It has attempted to generate material to put before ICSU members that will help guide their longer-term thinking on key issues and on ICSU's potential role in relation to these. The report is deliberately intended to provoke debate, and, by providing an information base on the future, to act as an input for internal discussions in ICSU and its member organisations.

1.2 Nature of Foresight

The project is concerned with recent science and technology Foresight exercises conducted since 1995. In terms of what is included as 'science', the study has focused on Foresight activities relating to the full range of sciences including to some extent the social and human sciences. As for what is meant by 'Foresight', one commonly used definition is as follows:

the process involved in systematically attempting to look into the longer-term future of science, technology, the economy, the environment and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits.[1]

However, we recognise that the concept goes under different names in different countries (for example, *la prospective*, 'futures' or *prospecçao*) and that definitions vary somewhat as a result. We have therefore adopted a fairly broad interpretation as to what should be included under the heading of 'Foresight'.

Nevertheless, there are a number of features that define 'Foresight' and distinguish it from forecasting. One is that Foresight is a highly consultative process that allows a range of those involved in science and technology (researchers, funders, 'users' of the results from research and so on) to obtain a better appreciation of the interrelationships between science, technology, the economy and society. Another key feature of Foresight is the starting assumption that there are many possible futures, and precisely which one we will arrive at depends on the choices we make now. Thus, Foresight involves a much more 'active' attitude towards the future than traditional forecasting. Foresight is not so much concerned with predicting the future as with shaping or even creating the future of our choice from the infinite range of possibilities available.

Why do countries (or organisations) carry out Foresight? The argument here is reasonably familiar. New generic technologies are likely to have a fundamental impact on society over coming decades. However, their development and exploitation is dependent on further advances in scientific research. Hence, we are witnessing the growing strategic importance of science and technology as we move towards a more knowledge-intensive economy and society. At the same time, the public funds for investing in science and technology are limited; governments cannot afford to finance all areas of science and technology on the scale that researchers would like. Consequently, choices have to be made, for example, choices as to which areas of scientific research should be carried out independently by an individual country, which are better pursued on the basis of international collaboration, and which ought to be left to other (perhaps richer) nations to develop. Where particular areas of science are chosen for public funds to be invested in them, those choices need to link science and technology and the outputs from research to societal needs. (It should be stressed here that 'Foresight' is taken to imply looking at the wider potential impact of science on society including the intellectual and cultural effects as well as enhancing the quality of life, and not just the narrow economic benefits in terms of wealth creation.) Foresight provides a process or policy tool to help make such choices.

1.3 Scope of Study

Over the last dozen years or so, numerous science and technology Foresight exercises have been carried out around the world. Most of these have been national Foresight exercises but some have focused on a (sub-national) region. There have also been a few that have been international in scope (in particular by the European Commission and the APEC Centre for Technology Foresight based in Thailand) or that have involved international collaboration (e.g. between

1. A similar definition was first developed in Irvine and Martin (1984) although it has subsequently been refined in later publications by Martin and colleagues. For a more detailed description of the nature of Foresight and of its evolution, see e.g. Irvine and Martin (1984 and 1989), Martin and Irvine (1989), Martin (1993, 1995a, 1995b, 1996 and 2001), and Martin and Johnston (1999). See also other articles in the special issue of *Technological Forecasting and Social Change*, Vol. 60, devoted to technology Foresight.

Japan and Germany). This study for ICSU includes these international Foresight efforts as well as a selection of the national Foresight exercises. For the latter, the countries covered include industrialised countries both large (e.g. Japan) and small (e.g. New Zealand), transition economies (e.g. Hungary, South Africa) and developing countries from different regions (e.g. India, Uruguay). The final choice of countries to ensure good coverage of different types of countries and economies was agreed in consultation with the Steering Group for the project and depended in part on the availability of appropriate reports describing the Foresight exercises and their results, as well as on the time and resources available for the study. It should also be noted that the study has concentrated on public-sector Foresight exercises conducted by governments, academies and international organisations rather than those carried out by private-sector organisations.

In view of the strong international interests of ICSU, special emphasis was laid on collecting material from transition and developing countries, even though this was often less formally presented as a Foresight exercise, as explained below. The notion of 'transition' is applied variously in different contexts, e.g. in describing political reorganisation (e.g. Eastern Europe), or economic 'catching up' (e.g. South-East Asia), or the shift to new knowledge-based technologies (in many countries including the 'developed'). Here we use it to cover countries with a technological base that is not sufficient for their socio-economic aspirations and where active efforts are being made to develop or extend it, often in conjunction with political restructuring. In other words, they have accumulated scientific capacity in certain areas and now look to raise other areas to similar levels. However, in practice, transition and developing economies form part of a continuous spectrum so in much of the later analysis in this study we treat them together.

The transition countries of Eastern Europe are nevertheless of special interest, not least because of the legacy in many of them of relatively large and powerful Academies of Science, which operated outside and above the realm of universities. This produced large numbers of well qualified scientists in orthodox scientific disciplines, typically the 'hard sciences', who had little impact, however, on the countries' technology systems except perhaps in the military field. Industrial R&D was carried out in other organisations, research laboratories and design bureaux, largely cut off from scientific contact. Since transition, the various Academies of Science have been supported to some extent but they are still struggling to find a role in which their members can make a more practical contribution, while the research laboratories and design bureaux have often disappeared. In particular, there is a need to stimulate cross-disciplinary interaction of the kind not encouraged by the previous structures. In the absence of appropriate supply and demand, many erstwhile members of the Academies (and universities) have moved at least temporarily to Western Europe and the USA (where, for example, there are now large numbers of immigrant scientists employed in Silicon Valley). Clearly, it would be desirable to retain more of this talent within the transition countries and even provide incentives for the outflow to return, and this may be judged to be a potential objective for ICSU policy consideration and supportive action.

The situation that many developing countries face is the problem of limited capacity for science and stretched resources in a context where other needs are often given priority. Some regard scientific advance in these countries as an expensive luxury but in our view that is a serious mistake. The conduct of science is essential for helping to meet the countries' specific technological needs. Moreover, the particular nature of their resources and their environmental context may permit them to make significant contributions in certain areas to the global supply of knowledge in those fields as well as applying that knowledge locally to help meet their own needs.

More generally, though less often emphasised, the conduct of science in developing countries is crucial for establishing an 'absorptive capacity'. Absorptive capacity is the ability to digest and utilise the results carried out in other countries. A basic finding of the literature on absorptive capacity over the past decade is that it cannot be acquired in a purely passive way – active efforts are required to undertake scientific or technological research of one's own. In other words, learning from and utilising work conducted elsewhere is likely to be more successful the more the good science that the country (or organisation) in question undertakes. Doing science oneself allows a much deeper comprehension of the achievements (and problems) of other predecessors, as well as building a base for one's own scientific progress. Clearly international science networks act as a major transmission mechanism for such absorption; furthermore, participation in the leading scientific networks has been shown to be boosted by raising the prestige of one's own science base. The more good science the developing country carries out, the more it is likely to come into contact with the best work at the frontier in other countries. Despite the problem of limited resources, science should therefore remain a priority for developing countries seeking to develop their 'absorptive capacity'.

In what follows, we look first at the approach adopted in identifying and collecting relevant material. Section 3 explains how the countries were selected for inclusion and how the Foresight material was analysed. It also describes the selection criteria used in identifying scientific issues of potential interest to ICSU and how these criteria were used to generate a medium-length list of areas (in Table 3) clustered under a number of headings. Section 4 contains a formal analysis of the relationship between scientific priority areas (as reflected in Foresight exercises) and type of country. The final section draws together the main conclusions to emerge from the study regarding scientific areas of potential interest to ICSU.

2. Approach

2.1 Identification of Relevant Material

SPRU has worked in close collaboration with ICSU in obtaining Foresight and related material from the countries selected for coverage. At the start of the project, ICSU contacted its national members for help in identifying and supplying Foresight material. This yielded 15 responses and various forms of Foresight material and related information.

Another early step was for the SPRU team to conduct a literature review in order to identify relevant material on recent[2] Foresight exercises. We also compiled a list of international contacts to be consulted for additional suggestions on Foresight literature and other material. Here, we drew upon SPRU's extensive network of international contacts.[3] Altogether, we sought the help of 62 experts who were particularly knowledgeable about Foresight activities. Of these, 50 (i.e. just over 80%) responded, these covering more than 20 countries and a number of international institutions such as OECD, APEC, UNIDO and the EU (see Table 1 below). They offered suggestions as to individuals or institutions to contact, sources of Foresight material or themselves provided Foresight reports.

Lastly, one of the authors (AT) carried out a systematic and detailed search of the Internet to identify and explore relevant web sites around the world and hence acquire further material from Foresight exercises in different countries.

On the basis of these various efforts, we identified over 30 countries that have conducted some kind of public-sector Foresight exercise in recent years. Some of these have carried out full Foresight exercises (covering the whole range of science and technology) while others have only conducted more limited exercises[4]. These are listed in Table 1 below.[5]

2.2 How the Material was Collected and Processed

The material on Foresight exercises was obtained in four main ways:

(a) for certain countries, SPRU already possessed Foresight reports and other documentation;
(b) a number of those contacted sent copies of Foresight reports by mail;
(c) some material was sent in the form of email attachments;
(d) in many cases, Foresight material was downloaded from the appropriate website.

An initial processing of the material was then carried out to establish whether it provided suitable information for further analysis. In some cases (e.g. Nigeria and Poland), there proved to be only rather general material about the future or only very broad scientific developments, with insufficient information on specific scientific priorities. In other cases, the emphasis was very much on technology rather than science. Such limitations influenced the final decision as to which countries should be included in the study. In addition, although the SPRU team was able to process material in French, Italian, Spanish and Portuguese as well as English, our ability to deal with other languages was a further factor that shaped the final choice of countries to be included.[6]

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2. 'Recent' has been defined here as those Foresight activities conducted since 1995.

3. This includes the extensive SPRU Alumni database consisting of several hundred former SPRU students and staff drawn from all round the world.

4. In a few instances, this might possibly be a consequence of the SPRU team only gaining access to some of the Foresight material for that country.

5. In some cases, we also obtained information on private-sector Foresight activities.

6. For example, the Philippines, Singapore and Thailand apparently only had material in their own languages. We chose to include APEC in the study because for countries such as these, while there was little material available in English, we could instead use English-language material from the APEC Centre for Technology Foresight in Thailand.

Table 1 – Material Collected from Different Countries[7]

Country	Region – Type	Foresight Material Analysed
Austria	Europe – IE	Technology Delphi Study, 1996-98; Regional Study for Salzburg, 1998
Australia	Australasia – IE	Matching Science and Technology Future Needs (2010), 1995-96
Belgium	Europe – IE	Belgian Federal Foresight Study, 2000-01 (Flemish)
Brazil	South America – TDE	Programa Brasiliero de Prospective Tecnologica
Canada	North America – IE	Industrial Technology Foresight, 2000
China	Asia – TDE	Technology Foresight for Priority Industries (2010), 1997-99
Czech Republic	Central Europe – TDE	Analysis of the Key Technology Lists
Denmark	Nordic – IE	Foresight Exercise – S&T
Finland	Nordic – IE	On the Way to Technology Vision, 1996-98
France	Europe – IE	Technologies Clés Foresight Exercise, 1999-2000
Germany	Europe – IE	FUTUR – Foresight in different areas (German)
Hungary	Central Europe – TDE	Technology Foresight Program, 1997-99
India	Asia – TDE	Technology Vision (up to 2020), 1996
Italy	Europe – IE	Foresight Programme, 2000-01
Ireland	Europe – IE	Technology Foresight, 1999
Japan	Asia – IE	7th Delphi Technology Forecast Survey, 2000-01
Netherlands	Europe – IE	Foresight Studies by Ministry of Economic Affairs, Technology Radar
New Zealand	Australasia – IE	Foresight Project
Nigeria	Africa – TDE	Vision 2010
Norway	Nordic – IE	Scenario-based Foresight Exercise, 1998
Peru	South America – TDE	Inventario Nacional de Recursos en Prospective Tecnologica Industrial
Philippines	Asia – TDE	S&T Master Plan, 1996
Portugal	Europe – IE	Engineering and Technology – University Foresight, 1999-2000
Singapore	Asia – TDE	Second National S&T Plan – panel-based Foresight
South Africa	Africa – TDE	National Research and Technology Foresight, 1998
Saudi Arabia	Middle East – TDE	List of Priorities for the Saudi Arabia Academy of Science 2002
South Korea	Asia – IE	Second Technology Forecast, 1998
Spain	Europe – IE	S&T Plan
Sweden	Nordic – IE	Foresight Exercise
Uruguay	South America – TDE	Programa de Prospective Tecnologica Uruguay 2015
USA	North America – IE	Office of Science and Technology Policy; Industrial Technologies
UK	Europe – IE	Office of Science and Technology Foresight Programme, 2000-01
International Organisations		
APEC	Asia-Pacific	Exercise by Centre for Technology Foresight for APEC region, 1998-99
OECD	IE	International Futures Programme, 1990; Future Trends 7: An Information Base for Scanning the Future, 2001-02
UN	Millennium Project	Foresight Study, 1999-2000
UNIDO		Technology Foresight for Latin America Program
EU	Europe, 2010	Scenario-based Foresight (2010), 1997-1999; Future Project, 1998

IE = Industrialised Economy, TDE = Transition or Developing Economy

7. The exercises listed in Table 1 are just the main examples of the material used; the full bibliography of references is given in the Appendix.

3. Methodology

3.1 Selection of Countries

The starting point here was the need to ensure that the main types of country – industrialised, transition and developing – were fully covered (but that no type was over-represented). The aim was to ensure full coverage of the different approaches to Foresight that these different types of economies, with their respective problems and social structures, have adopted. Efforts were also made to ensure that the countries selected covered a range of sizes, levels of economic development, cultures and regions. In regions such as Africa, where examples of 'Foresight' (more strictly defined) are comparatively rare, this entailed adopting a somewhat broader definition of 'Foresight' that included scanning reports on science and development, and on national scientific priorities as well as considering regional and international reports (for example, by the World Bank). Particular care has been taken in this study to ensure that the findings are not seen as attempting to impose the interests of industrialised countries on developing countries. For example, we have tried to identify cases where the world scientific community might fruitfully collaborate with and draw upon indigenous science.

As noted in the previous section, the choice of countries was also influenced by whether or not there was suitable Foresight material available (not too general nor too focused on technology rather than science) on which to base a full analysis.[8] The 22 countries that were finally included in the study are listed in Table 2 below.[9]

Table 2 – List of Countries Included

Type	Region	Country	Size of Country/Economy
Industrialised Countries	Western Europe	France	Large
		Germany	Large
		Spain	Large
		UK	Large
		Austria	Small
		Ireland	Small
		Finland	Small
	North America	USA	Large
		Canada	Medium
	Australasia	Australia	Medium
		New Zealand	Small
	Asia	Japan	Large
Transition and Developing Countries	Central Europe	Hungary	Medium
	Middle East	Saudi Arabia	Small
	Africa	South Africa	Medium
	Indian subcontinent	India	Large
	Asia	Singapore*	Small
		China*	Large
		Philippines*	Large
	South America	Brazil	Large
		Uruguay	Small
		Peru	Small

* Included as part of APEC exercise rather than as a separate country.

3.2 Analysis of Material

Having obtained the reports on Foresight exercises conducted in the various countries, we critically reviewed and analysed the main results from those exercises. This involved first reading all the material collected and classifying the Foresight exercises by country and region. Next, we examined the content of the Foresight exercises which ranged from the very specific to the most general in terms of covering the full range of science (and in particular the six main fields identified below). Some exercises focused on science and some more on technology. For the latter, in certain cases (especially developing and transitional economies) this reflected the economic or political necessity of addressing urgent national problems and developing appropriate public policies. However, some of the larger transitional and developing economies do give more emphasis to science in their Foresight exercises because they recognise that science policy has an important role to play in the development process as well as technological and industrial policies. Those countries where the Foresight was either much too general or too focused were dropped from further consideration.

In some cases, the scientific areas that were seen as likely to prove the most important for that country or region over coming years were clearly listed. In other cases, reports had to be closely read in order to identify what were seen as the most important areas, and suitable 'labels' or short titles for each of these then had to be devised. Another problem encountered was that the level of specificity of the priority areas identified varied from one Foresight exercise to another. In some, the scientific priorities identified were rather general (e.g. biotechnology), while in others they were much more specific (e.g. rapid disease-diagnostic systems based on PCR:Polymerase Chain Reaction). In the latter cases, it was sometimes possible to synthesise a number of very specific scientific developments under one or more broader areas.

The above analysis generally resulted in a long list for each country of new and emerging developments in science and technology that are seen as likely to have a major impact on society over the next five to thirty years, and these were then listed in tabular form.

3.3 Criteria for Selection of Key Scientific Areas

The next stage in the analysis was to identify from this extensive range of material those emerging issues in science and society where ICSU might have a central role to play. The approach was for the SPRU team to begin by proposing a set of specific selection criteria for identifying which potential developments are likely to be most pertinent to ICSU's mission. These were then discussed and refined with the ICSU Steering Group for the project. It was agreed that the selection criteria should include the following:

(A) Scientific potential

- research areas where significant scientific advances are likely over the next five to ten years and where the necessary resources are likely to be made available to enable those scientific advance to take place (e.g. genomics, nanotechnology)
- research that responds to scientific needs, generating advances that in turn open up possibilities for other scientific developments or fields (e.g. new research instrumentation, modelling and simulation techniques)

(B) Collaboration potential

- research that requires, or at least will greatly benefit from, international or global collaboration (e.g. environmental sciences, space research)
- research that offers new possibilities in terms of approaches to multi- or inter-disciplinary co-operation, in particular to address complex problems with global ramifications (e.g. global warming, ageing)

(C) Potential impact

- scientific developments that are likely to result in major benefits to society, whether in the form of wealth creation, improved quality of life or protecting the environment (e.g. new materials, earthquake prediction)
- scientific developments that are linked with ethical issues – for example, developments that are likely to widen the gap between rich and poor (e.g. new but expensive medicines), or that may result in the production of knowledge

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8. ICSU offered all member countries the opportunity to provide material for the study, and in several cases further efforts were subsequently made to seek out any relevant material. For countries where no material was forthcoming, this meant that they had to be excluded from further consideration.

9. For countries where suitable Foresight material was available but which were excluded, this was primarily to ensure that certain types of countries or regions (e.g. Northern Europe) were not over-represented.

that is at odds with moral sensitivities (e.g. stem cell research), or where there could be cultural or political influences on priorities for knowledge production (e.g. relating to the role of women, health care, defence, or social justice versus individual liberty)

(D) POTENTIAL FOR DEVELOPING COUNTRIES

- areas where developing countries have some advantages in relation to scientific collaboration (e.g. drawing upon traditional medicines, flora, fauna and geographical assets)
- research that offers opportunities for capacity-building especially in key areas for developing countries (e.g. agricultural science, alternative or renewable energy)

Using the agreed selection criteria, the SPRU team analysed the scientific areas identified in each Foresight exercise, and attempted to rate them in relation to each of the above criteria. This was done, where possible, on the basis of the information contained in the Foresight report, but in many cases the SPRU team had to use a degree of judgement in rating each area in terms of all the various criteria. Consequently, the ratings attached to the scientific areas listed in Table 3 should merely be viewed as a **starting point** for ICSU discussions rather than as a definitive judgement of how well each scientific area meets the selection criteria.

It should also be stressed that the ratings in many cases also involved a degree of generalisation or simplification. This is a particular problem in relation to the two criteria relating to developing countries. For example, in the case of a given scientific development, there may well be one or two developing countries that might be capable of making a significant scientific contribution while the great majority of developing countries may lack the scientific capacity to do this. As a result, ratings for the two criteria relating to developing countries are inevitably somewhat subjective and are not given in Table 3.

From the ratings, the SPRU team identified those scientific areas that appeared to meet the selection criteria most closely, and thus drew up a medium-length list of scientific areas where ICSU could have an important role to play. In many cases, this meant combining slightly different but closely related priority areas[10] identified in separate Foresight exercises, perhaps altering the terminology slightly to accommodate this combination.[11] It should also be stressed that it is not essential that a scientific area meets all the selection criteria for it to be important to ICSU. For example, it may not be essential that a scientific development is likely to raise ethical issues, although many of the areas are associated with such issues.

To check the robustness of this approach (and in particular that it was not too dependent on subjective interpretation), two members of the team each independently produced a medium-length list. The two lists were then compared and found to be broadly similar. The main difference concerned the appropriate degree of specificity for the identified scientific areas (i.e. in one case, some of the scientific areas were a little broader or more general, while in the other they were somewhat more specific). After a discussion among the team as to how best to resolve this, the two lists were then combined.

The preliminary medium-length list was discussed in detail at a meeting with the ICSU Steering Group and various improvements were agreed. Another draft was then circulated for comment by the Steering Group, and a few more changes were made in the light of the suggestions. Further refinements were made after discussions with the ICSU Committee on Scientific Planning and Review and subsequent correspondence.

3.4 Clustering of Scientific Areas

Discussions with ICSU Steering Group not only led to a refinement of the list of scientific areas included in the medium-length list, but also to a classification of those areas into six main 'clusters' or categories. These were:

(i) life sciences and biotechnology;
(ii) human health;
(iii) environment and sustainable use of natural resources;
(iv) energy;
(v) information and engineering technologies;
(vi) materials science.

The results are shown below in Table 3 below. However, it should be noted that in some cases there is an element of arbitrariness as to whether a given scientific area should be included under one category rather than another. In such cases, the alternative category is indicated in 'curly' brackets – e.g. {HEALTH}.

10. For example, different Foresight exercises referred variously to telemedicine, telecare and e-health, topics which were combined under one heading in our medium-length list.

11. This explains why in several instances the ratings given for a particular scientific area in Table 3 may differ from the ratings given in the national tables.

Table 3 – Priorities Identified in Foresight Exercises and Relevance to Selection Criteria – Medium-Length List

COUNTRY	SCIENTIFIC DEVELOPMENT	CRITERIA: Scientific Potential – Major scientific advances in 5-10 years	CRITERIA: Scientific Potential – Impact on other sciences	CRITERIA: Collaboration Potential – International collaboration opportunities	CRITERIA: Collaboration Potential – Multi/inter-disciplinary opportunities	CRITERIA: Potential Impact – Major societal benefit	CRITERIA: Potential Impact – Ethical issues
	LIFE SCIENCES & BIOTECHNOLOGY [12]						
Australia, Brazil, Canada, France, Hungary, Ireland, Japan, S Africa, Spain, UK, US, APEC	**Human genetics, functional genomics etc.** - identify disease-related genes/ proteins, bio-informatics, gene therapy {HEALTH} [13]	YES	YES	YES	YES	YES (for some people/ countries)	YES
Canada, Hungary, Peru, UK, Uruguay	**Animal genetics** - e.g. transgenic animals for organ transplants (xenotransplantation) {HEALTH}	YES	YES? [14]	YES	SOME	YES (for some)	YES
Australia, Brazil, Canada, Finland, France, India, Ireland, Japan, Peru, S Africa, UK, US, Uruguay, APEC	**Genetic modification of food/crops** - e.g. crops using less water, saline/disease/pest resistant, fuel-producing crops, plants for bioremediation {ENVIRONMENT, ENERGY}	YES	YES?	YES	SOME	YES	YES
Brazil, Canada, India	**Pest control** methods, biopesticides {ENVIRONMENT}	YES?	MAYBE	YES	YES	YES	YES
Brazil, Germany, Hungary, Peru, S Africa, US	**Biopharming** - using natural products/active ingredients for pharmaceuticals etc. {HEALTH}	YES	MAYBE	YES	YES	YES	YES
Australia, Brazil, France, Ireland, Peru, S Africa, S Arabia, Uruguay, US, APEC	**Other biotechnology** – e.g. producing antibiotics/ enzymes using micro-organisms, 'gene machines' to make new proteins {HEALTH}	YES	YES	YES	YES	YES	SOME
Australia, Hungary, APEC	**Intellectual property** and knowledge-regulation, control {ALL OTHERS}	YES	YES	YES	YES	YES	YES
	HUMAN HEALTH						
Australia, Brazil, France, Hungary, Peru, S Africa, Spain, UK, US, APEC	**Telecare**, telemedicine, e-health, home diagnostic systems{ICT}	YES	SOME?	YES	YES	YES	SOME?
Austria, Brazil, France, Japan, UK, US	**Medical & supportive technologies** for elderly & disabled	YES	MAYBE	YES	YES	YES	SOME?
	ENVIRONMENT & SUSTAINABLE USE OF NATURAL RESOURCES						
Brazil, France, NZ, Peru, S Africa, Spain, US	**Biodiversity** - bio-mapping, inventory/ databases, conservation/ maintenance of biodiversity {BIOTECH}	YES	SOME	V LARGE	YES	YES	YES
France, Ireland, Japan, S Arabia, S Africa, US	**Resource management** - e.g. remote sensing, modelling & forecasting, data management, risk assessment (see below)	YES	SOME	LARGE	YES	YES	?
Brazil, Peru, S Arabia, S Africa, UK	**Soil** science, prevention of degradation/erosion/ desertification/pollution	YES	MAYBE	YES	YES	YES	?
Canada, France, Ireland, UK	**Bioremediation** - use of natural & engineered organisms to clean up pollution {BIOTECH}	MAYBE	**NO**	YES	YES	YES	?

		CRITERIA					
		Scientific Potential		Collaboration Potential		Potential Impact	
COUNTRY	**SCIENTIFIC DEVELOPMENT**	Major scientific advances in 5-10 years	Impact on other sciences	International collaboration opportunities	Multi/inter-disciplinary opportunities	Major societal benefit	Ethical issues
	ENVIRONMENT & SUSTAINABLE USE OF NATURAL RESOURCES						
Brazil, Japan, S Africa	**Air pollution** - esp'y real-time measurement of distribution & dynamics e.g. via space observation	YES?	SOME?	YES	YES	YES	**NO**
Brazil, France, India, Japan, S Africa, S Arabia, APEC	**Water recycling** – treatment and re-use of waste water from sewage, 'grey water', storm water {BIOTECH}	MAYBE	**NO**	YES	SOME	YES	**NO**
Brazil, France, Japan, Peru, S Africa, UK, APEC	**Water use saving/ efficiency** technologies (e.g. GM crops using less water) {BIOTECH}	YES?	**LITTLE?**	YES	YES	YES	?
Japan, UK	**Carbon sequestration** - CO2 fixation to protect global environment {ENERGY}	MAYBE	**NO**	YES	YES	YES	SOME
Brazil, France, Japan, S Arabia, Spain, US	**Recycling** – new techniques & products, separating garbage & recycling valuable materials {MATERIALS}	MAYBE	**LITTLE?**	YES?	YES	YES	**NO**
Japan, UK	**Risk & disasters** (environmental, natural, man-made, food etc.) - assessment, databases, management, emergency info & security systems	YES	SOME	LARGE	YES	YES	SOME
Australia, Brazil, Japan	**Flood** risk/rain damage prediction & prevention	MAYBE	**NO**	YES	YES	YES	**NO**
Australia, Brazil, Japan, S Arabia, S Africa	**Weather & climate** modelling, simulation & long-range forecasting	YES	SOME?	YES	YES	YES	**NO**
	ENERGY						
Brazil, Germany, Ireland, India, Japan, Peru, S Africa, UK, US, Uruguay	**New/renewable, clean energy** sources (e.g. biomass, wave, wind, hybrid systems); also energy storage {ENVIRONMENT}	YES	MAYBE	YES?	YES	YES	**NO**
Australia, Brazil, Finland, India, Japan	**Solar cells** – practical use as energy resource	MAYBE	**NO**	YES?	SOME	YES	**NO**
Brazil, UK	**Fuel cells**	MAYBE	**NO**	POSSIBLY	YES	YES	**NO**
	INFORMATION & COMMUNICATION TECHNOLOGIES						
Australia, Canada, India, Ireland, Hungary, Spain, UK, US	**Sensors** - biosensors, artificial senses + sensors directly stimulating nerves, integrated intelligent sensors (e.g. for biometrics), environmental sensors {HEALTH, ENVIRONMENT}	YES	YES	YES	YES	YES	SOME?
	MATERIALS SCIENCE						
Australia, Brazil, France, Germany, Ireland, S Africa, UK, US, APEC	**Biomaterials** - including bio-compatible materials, biomimetic materials etc.	YES	**NO**	YES	YES	?	**NO**
Brazil, Canada, France, Hungary, S Africa, UK, US, APEC	**Nanotechnology** - including nanofabrication	YES	YES?	YES	YES	YES	**NO**
Australia, Brazil, Finland, France, India, Japan, US, APEC	**Superconducting materials** e.g. superconducting at room temperature, superconducting magnets	MAYBE	MAYBE	?	?	?	**NO**

12. The scientific areas have been clustered under a number of main headings. / **13.** { } indicates where there is considerable overlap with another cluster. / **14.** Question marks in this table indicate a lower degree of confidence in the assessment.

4. Relationship between Scientific Fields and Type of Country

Before discussing the general conclusions to emerge from Table 3, it is worth conducting a more formal analysis of the association between the scientific areas identified in Foresight exercises and the different types of country included in the study. Correspondence analysis was used for this task, with the data being based on the full set of Foresight priorities of the countries considered here (as opposed to the medium-length list in Table 3). Because the areas ranged more broadly than did the medium-length list, we disaggregated them somewhat more extensively, classifying them into eight fields – Biological, Health, Chemicals, Environmental, Energy, Information Technology/ Electronics, Mechanical, and Materials. Thus, in addition to the categories in the medium-length list, we also identified for this analysis a group of 'Chemical' sciences (not overtly related to biological sciences), while sensors (other than biosensors) were included with other instrumentation and robotics in a 'Mechanical' category, differentiated from the ICT-based electronics field ('Electronic').

The analysis involved counting the number of sub-fields which each country included in its Foresight study, after classifying each of them into one or other of the eight principal fields. Clearly there is a certain amount of arbitrariness in how different countries specify their fields and sub-fields; for example, some give broad categories such as 'biotechnology' and 'genomics', while others break topics down in great detail. It is also noticeable that different countries may classify particular specific technologies under different headings (e.g. the USA's 'living systems' category covers environmental as well as biological topics), but these were reassigned here to our own list of main fields. One problem with our classification is that a single main field had to be chosen for each sub-field, whereas many had two possible categorisations – for instance 'nuclear waste disposal' could be classified as either 'energy' or 'environment'. We tried as far as possible to maintain consistency across countries, which is the primary concern here, but it should be recognised that other classifications might lead to somewhat different results. Consequently, the outcomes should be treated with some caution, but the findings nevertheless help underpin the general conclusions in Section 5.

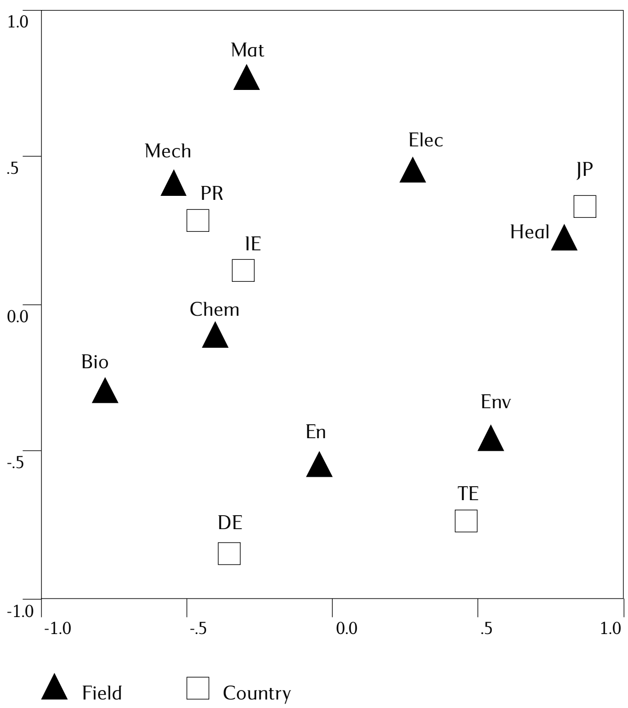
The study was carried out for all countries for which more detailed information was available. These were grouped into five categories:

1) seven 'industrial economies' of Western and Northern Europe (Austria, Finland, France, Germany, Ireland, Spain and the UK), referred to as 'IE';
2) five countries or regions of the Pacific Rim (USA, Canada, Australia, New Zealand and the multi-country group of APEC countries), referred to as 'PR';
3) Japan ('JP') was separately identified, both because of its unusually long list of Foresight projects (running to 15 pages of our compiled data) and because of its different resource/technology composition as compared with, say, the USA;
4) three 'transition economies' in various regions (Hungary, Saudi Arabia and South Africa), referred to as 'TE';

15. The data could in principle be subdivided accordingly, but were deemed to be too incomplete to warrant doing so here.

16. Correspondence analysis is a procedure for applying the mathematical techniques of multivariate analysis to statistical situations usually studied by simpler tests of 'association' such as chi-square and contingency tables. Chi-square analysis is a standard procedure for evaluating the independence of a set of rows of categorical data from a set of columns, where the rows possess one common attribute and the columns another. If the chi-square statistic for the difference between observed and 'expected' values is large enough (for a given number of degrees of freedom), the null hypothesis of no association between the rows and the columns can be rejected. However, in a data set with many rows and columns it may not be obvious which rows and which columns are influencing the outcome, which is reflected in just one statistic, nor what the general pattern of association actually is. Correspondence analysis brings in the use of multivariate analysis for the purpose of 'data reduction' – i.e. simplifying the multi-row, multi-column structure into a two-dimensional (or if required three-dimensional) format. This is most simply represented by a plot of transformed values, which reveals the overall association between each of the rows and each of the columns.

Row and Column Points



5) four 'developing economies' (Brazil, India, Peru and Uruguay), denominated 'DE'.

In the correspondence analysis, the eight 'scientific fields' were entered as rows and the five 'country types' as columns. A total of 946 sub-fields were counted, including many duplications from one country to the next. The resulting plot of the results is shown in the figure. While we need not concern ourselves here with the details of the methodology,[16] in essence the procedure tries to co-locate the two sets of data according to their distance from or proximity to each other. The row points representing scientific fields are shown as solid triangles and the column points representing types of country as open squares. Their location on the grid is determined by the fact that each country type has a profile made up the various scientific fields, and *vice versa*. As a result, we can interpret a finding that a country point and a field point are close together (for example, Japan is close to Health) as indicating a relative predominance of that field in that type of country. Equally, a large distance separating a country type and a field (e.g. developing economies and Materials) shows a relatively low emphasis on such a field in such countries.

Overall, the level of significance of the chi-square is high (χ^2 = 119.2, sig. = .000) but the amount of explanation conveyed is not particularly great ('inertia' = .078). This indicates that there is considerable similarity in scientific fields across all five types of country or region, so one should be able to find areas of common priority spanning all types of country. However, as we shall see below, there are some significant differences.

The most interesting dimension with regard to country type is the vertical one, which has the three types of 'industrialised economies' in the upper part (PR, EU and JP) and the transition and developing economies in the lower part.[17] As already noted, the key issue is how closely co-located are the fields and the country types. In the vertical dimension, Materials, Electronics, Mechanical and Health lie in the upper part of the plot – i.e. more associated with the industrialised economies. This might be explained in terms of developing countries tending to be more users of these technologies than originators of them. The bottom four fields – Biological, Chemical, Energy and Environment – by contrast all lie between the developing/transition economies (DE and TE) and the industrialised ones, in the vertical dimension. These would seem to represent areas where global interaction might be greatest, given that all types of country share considerable Foresight interest in these fields.[18] This finding therefore supports the concentration in Table 3 on such fields as potential priorities given the likelihood of international commonalities and joint contributions. This point is enlarged upon in the concluding section.

17. Being nearer the top or the bottom has no meaning in itself – the algebraic signs could just as easily be reversed to show the transition and developing economies at the top.

18. However, it should be noted that within each main field there may be further differences – for instance, within the Biological field industrialised countries are more likely to focus on functional genomics and developing economies on biopharming.

5. Discussion and Conclusions

As emphasised earlier, it is not the intention of this report to arrive at a short list of, say, the three or four most important scientific developments for ICSU to focus its attention upon. Instead, the aim is to provide suitable material to prompt a fruitful ICSU discussion out of which a scientific agenda will in due course emerge. In particular, ICSU members, by virtue of their scientific knowledge, may well have rather different judgements on whether major scientific advances are likely in a given area over the next five to ten years, or on the likely impact on other sciences, or on the extent to which that field is likely to be a priority for capacity-building in developing countries. They may therefore arrive at a different short list than the SPRU team would if it were to attempt to do this with its much more limited or general 'lay' knowledge of different scientific fields. Consequently, this final section will not go into great detail about each of the scientific developments listed in Table 3. Instead, it will offer some general observations that may be useful in structuring the ICSU discussions and the effort to arrive at an agreed scientific agenda for ICSU.

5.1 Categorisation of the Priority Areas

The first observation concerns the nature of the 28 scientific areas listed in Table 3, with 12 being categorised under the heading of 'Environment and sustainable use of natural resources', followed by 'Life sciences and biotechnology' with seven areas, while there are only three areas listed under 'Materials science', and just one under 'Information and communication technologies'. There will undoubtedly be some who will be surprised and perhaps disappointed that the physical sciences and engineering do not feature more prominently in this list. Others may wonder why mathematics, for example, is not mentioned. This may be because mathematics, while it underpins many scientific fields, is 'hidden' beneath the surface of the areas that emerge as priorities from Foresight exercises. Similar considerations may apply in the case of social sciences. However, ICSU members with their detailed scientific knowledge are obviously in a far better position than SPRU to identify underpinning sciences for the various developments listed in Table 3.

There are several factors that may have contributed to the preponderance of areas in environmental and life sciences. The first is that many Foresight exercises in the last ten years have suggested we are witnessing a fundamental shift in emphasis from the physical sciences to the life and environmental sciences. Whereas physics was, for many decades of the 20th Century, arguably the dominant scientific discipline in terms of fundamental discoveries, theoretical advances and its influence on other fields (not to mention its success in attracting some of the best scientists to its ranks), we now appear to be moving into an era in which rather more of the scientific 'action' in terms of discoveries and advances in theoretical understanding seems to be taking place in life and environmental sciences. In part, this may be a consequence of faster growth in funding for life sciences, and in the number of students favouring life and environmental sciences, especially women students.

Secondly, in many countries there has been a substantial shift in the 'social contract' between science and society in the last decade or so.[19] Governments are increasingly expecting that public funding for research will lead to results that produce fairly direct and specific benefits for society.[20] Science is being expected to address society's needs much more closely than was the case in the period from 1945 to the late 1980s. Among the societal needs that are currently most prominent are those that relate to enhancing the quality of life – and more specifically to improving human health[21] and to protecting the environment. This may therefore be another factor contributing to the preponderance of areas under the life sciences and environmental sciences categories.

A third factor relates to the selection criteria employed here for identifying scientific areas of potential interest to

ICSU. In particular, advances in life sciences and environmental sciences are perhaps more likely to produce a major societal benefit in the medium term than advances, say, in physics where the timescale may be several decades. They are also more likely to be linked with important ethical issues, and to be a higher priority for capacity-building among developing countries, two of the other selection criteria used here. In addition, while advances in physical sciences and related branches of engineering may well contribute to new technologies that yield economic benefits, the growing competition between nations experienced over the last two decades may reduce the opportunities for the type of international scientific collaboration that ICSU might sponsor.

5.2 Scientific Areas Listed in Many Foresight Exercises

A second conclusion to emerge from Table 3 is that certain scientific areas were identified in a large number of the Foresight exercises analysed. Two of the most prominent examples are the genetic modification (GM) of food or crops, which featured in 14 of the Foresight exercises examined, and new/renewable clean energy sources, which featured in ten. It is significant that in both cases developing or transition countries were just as likely to list these areas as industrialised countries. The former is an area that appears to meet all of the selection criteria, although the scope for multi-disciplinary collaboration is perhaps not quite as great as that for some other areas, and it is likely that only a few developing countries will have the scientific capacity to make a significant contribution. Other issues to be considered for the GM area are whether it is perhaps too late for ICSU to have a significant impact, and the possibility of competition or even opposition from companies to any ICSU initiative. The new/renewable energy area likewise meets most of the criteria (although it may be less likely to raise major ethical issues). However, 'new/renewable energy' may be too broad an area, as it is very heterogeneous in terms of the science,[22] and it would require some care to develop a coherent theme for ICSU. The special relevance of biomass to many in the developing world where there is a shortage of wood for fuel might commend it for special attention, especially since it is not necessarily negative for CO_2 emissions.

Three other areas appearing in many Foresight exercises are human genetics and functional genomics (identified in 12 of the exercises), 'other biotechnology' (a residual category that includes specific areas such as the production of antibiotics or enzymes using micro-organisms, and 'gene machines' to make new proteins) and telecare (both mentioned in 10 exercises). In all three of these cases, the scope for developing or transition countries to contribute is generally rather limited (with one or two prominent exceptions), and the area is unlikely to be a top priority in relation to their capacity-building efforts (although it is notable that all three were cited as priorities by Brazil and South Africa as well as in the APEC study). Similarly, sensors, an area listed in eight of the national Foresight exercises, would seem to be more of relevance to industrialised countries (although India has a strong interest in the area). The same is broadly true of medical and supportive technologies for the elderly and disabled, biomaterials, nanotechnology, and superconducting materials (although Brazil is interested in all of these, and South Africa and APEC in several of them). With a number of these areas there is also a question of whether countries would be willing to collaborate, or whether the element of international competition would be too great.

In contrast, four areas that are apparently of stronger interest to transition and developing countries than industrialised nations are those to do with biopharming (using natural products, and more specifically their active ingredients, for pharmaceuticals etc.), soil science (including the prevention of soil degradation, erosion, desertification and

19. For a more detailed analysis of this shift in the social contract for science, see, for example, Guston, and Keniston (1994), Lubchenco (1998) and Martin (2002).

20. It should be remembered that Foresight normally involves a process of dialogue between researchers, funders (normally government agencies) and users so the resulting scientific priorities that emerge will reflect the underlying social contract between science and the state.

21. lSome might wonder why there are not more areas listed under the 'human health' category in Table 3. The main explanation is that the Steering Group emphasised that the areas selected for Table 3 must embody an interesting scientific issue if they were to be of potential interest to ICSU. Many of the health-related priorities identified in Foresight exercises are more concerned with medicine or medical technology where the scientific element is less central. Moreover, health-related areas where the science is crucial are often more likely to be classified under the 'life sciences' category rather than 'human health'.

22. Consider fusion versus fuel cells versus biomass versus wind and tide versus solar.

soil pollution), water recycling, and the closely related area of water-use saving/efficiency technologies. The first of these three areas appeared as a priority in six of the national Foresight exercises analysed here, the second in five, and the third and fourth in seven. As noted in the following section, biopharming would seem to meet all the selection criteria and may therefore be of particular interest to ICSU. However, the third and fourth areas are perhaps more likely to involve technology than science.

It should, however, be stressed at this point that ICSU, in discussing its future scientific agenda, might deliberately choose to highlight scientific areas that do **not** feature so prominently in Foresight exercises. Because Foresight priorities emerge from a process of dialogue between the scientific community, government, and users in industry and elsewhere, those priorities may tend to downplay the significance of certain scientific fields, particularly those where the links between basic research and exploitation in the form of new technology and innovation are longer-term, more diffuse or indirect. ICSU could, for example, decide that physical sciences and mathematics were potentially at risk because they often feature less prominently in Foresight exercises than life and environmental sciences, and that ICSU's role was to reinforce them in some way.

5.3 Scientific Areas that Best Meet the Selection Criteria

Several of the areas listed under the 'life sciences and biotechnology' category appear to meet essentially all of the selection criteria employed in this project.[23] These include the genetic modification of food or crops (already mentioned above), pest control methods (including biopesticides), biopharming, and intellectual property (not strictly a 'scientific' topic, but one that is nevertheless potentially of great interest to ICSU members). With all of these, however, there may be elements of economic competition or opposition from industry that may hinder international collaborative research efforts.

Under the other broad categories, areas which rate highly in relation to the selection criteria include medical and supportive technologies (especially for the elderly and disabled), biodiversity (including bio-mapping, the development of a comprehensive inventory or set of databases on biodiversity, conservation and the maintenance of biodiversity), and risk and disasters (covering environmental, natural, man-made and food risks, and including risk assessment, construction of databases on risk, risk management, providing emergency information on risks or disasters, and developing appropriate security systems). Of these three areas, the first is perhaps more concerned with technology than science, while the other two may be a little too broad and ICSU may need to consider focusing on a specific aspect such as the development, standardisation and integration of databases. Nevertheless, if meeting all the selection criteria were deemed to be important by ICSU, then these areas and those listed in the previous paragraph would appear to be amongst the leading candidates for further discussion.

5.4 Concluding Comments

As was observed in Section 4, one conclusion to emerge from this study is the broad similarity of the scientific areas identified as priorities across all types and sizes of countries, which gives cause for optimism that it should be possible for ICSU to agree a number of scientific developments that would benefit from international collaboration. Nevertheless, there are certain differences in the nature of the Foresight priorities identified between developing/ transitional economies and industrialised nations. In particular, the former tend to focus more on technological areas as well as on developments needed to solve their more immediate problems, and they place less emphasis on more basic scientific areas and on the 'hard sciences'. Conversely, the developed world's priorities are often driven by its 'problems of success' – for example, keeping people living longer – and unfortunately these may crowd out of the priorities of the developing world. In view of the common denominator of underlying science, if not of detailed priorities, however, there would appear to be a role for ICSU to indicate actions that might begin to remedy this situation.

23. As noted earlier, it is not essential that an area meets **all** the selection criteria for it to be important to ICSU.

Let us end with a reminder that this study forms part of a wider attempt by ICSU to identify emerging scientific developments that might form part of its agenda. As was stressed earlier, the SPRU study is certainly not intended to be the end-point of this initiative but merely one step in a longer process. We have tried to generate material that will help guide the longer-term thinking of ICSU on key issues and on its potential role in relation to these. The report aims to provoke debate within ICSU and its member organisations. It is intended that the medium-length list of scientific developments emerging from Foresight exercises and summarised in Table 3, together with the preliminary assessments of each in terms of the agreed selection criteria, should form the basis of discussions among ICSU members, in particular at the ICSU General Assembly in September 2002. From these discussions may emerge a clearer and better informed view as to what should be the scientific agenda for ICSU in coming years.

Appendices

Appendix 1 – Country Tables

The tables of scientific areas emerging as priorities from national Foresight exercises are available on request from ICSU. They are also available via ICSU website (http://www.icsu.org/ Library/ProcRep/CSPR/SPRU0702-Appx1.pdf).

Appendix 2 – References to Foresight Material Analysed in the Study

Australia

• Australian Science Technology and Engineering Council (ASTEC), *Developing Long-Term Strategies for Science and Technology in Australia; Outcomes of the Study: Matching Science and Technology to Future Needs 2010 – Parts I-III,* Canberra, 1996.

http://www.dist.gov.au/science/astec/astec/future/final/futurea.htm

Austria

• Federal Ministry of Education, Austrian Academy of Science and Institute of Technology Assessment, *Technology Delphi, Delphi Study, 1996-1998,* Vienna, 1998.

http://www.bmwf.gv.at/4fte/materialien/delphi/index.htm

Brazil

• Secretaria de Tecnologia Industrial, Ministerio do Desenvolvimento, Industria e Comercio Exterior, *Programa Brasileiro de Prospectiva Tecnologica Industrial,* Brasilia, 2000.

http://www.mdic.gov.br/progacoes/tecnologia/programabrasileiropti.html

Canada

• National Research Council Canada, *Industrial Technology Foresight: Needs and Science Horizon Priorities,* Ottawa, 2000.

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