

## Health & Life Sciences

### The Sector

The sector is based around health promotion and health care activities, along with the pharmaceutical, medical instrument and equipment industries that support them, and biotechnology and veterinary medicine to the extent that they share a common research base. Advances in the life sciences also present opportunities in other economic sectors such as agriculture, food, or materials, and the panel has taken a broad view of the opportunities in prioritising research areas.

### The Future

The panel expects the ageing populations in the developed world, and the consequent increase in chronic disease and disability, to have a major impact on health care needs (see figure). Changes already under way in the organisation of health services and the structure of the pharmaceutical industry will determine how this demand is translated into innovation. At the same time progress in molecular genetics and the application of information technology to health care will offer expanding opportunities. Environmental pressure may drive innovation in biological production and animal health.



### Key Recommendations

The Health and Life Sciences panel recommend greater effort and investment in:

- Infrastructure for exploitation and development. Economic success in the expanding life sciences sector needs close links between industry, health services, and a strong research base in the life sciences and clinical medicine.
- "Integrative biology": research programmes which integrate molecular biology and genetics with cell and tissue biology, and whole organism studies.
- Neuroscience and the cognitive sciences. Research into progressive degenerative disease and non-specific, age-related decline.
- Ageing. Basic research into ageing and disabling degenerative disease, coupled with technologies for sustaining reasonable quality of life for the elderly infirm.
- Genetics in risk evaluation and management. Understanding how genetic information can be applied to preventing and treating common multi-factorial diseases.
- Drug creation and delivery. Building the molecular, chemical, and biological

expertise that will support new classes of therapeutic agents.

- Advanced recombinant technology. Research into key metabolic pathways, metabolic engineering, and applications in the biological manufacture of industrial products.
- Diagnostic applications of molecular biology. Applying research into disease at the genetic, molecular and cellular levels to develop new generations of diagnostics.
- "Immune manipulation". Research into the control of the immune system, and applications in specific interventions in inflammatory and immune disease, vaccines, transplants and other areas.
- Medical information technology. Innovative ways of using information and communication systems to inform and support clinical decisions, and medical practice in general.



## Forward with Foresight

### Practical steps to implement recommendations

The panel's report includes detailed suggestions on how each recommendation might be implemented. The action needed is different in each area, but broadly speaking, four types of initiative are envisaged:

- Strategic research programmes to develop basic knowledge underpinning specific areas of opportunity. These would involve focused, co-ordinated action by both public- and private- sector research groups.
- Basic research programmes to develop a broad and expansive knowledge base in major areas of long-term importance, involving public-sector, and in some cases private sector researchers.
- Developing the infrastructure for life sciences research and exploitation by changing regulations, organisational structures, and resource allocation. Specific initiatives include:
  - improving the fiscal environment for new company formation and funding;
  - improving the interface between academic research and industry through career flexibility, training, and further development of university technology transfer groups;
  - modifying the Research Assessment Exercise to provide greater incentives for co-operative research programmes in the university sector;
  - additional technology incubators;

- greater investment in the physical infrastructure for life sciences research in universities

The panel also recommends changes in organisation and training to strengthen clinical research within the health services.

- Undergraduate and postgraduate training programmes to accelerate development of new cadres of researchers with the expertise to address emerging areas of long-term importance.



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**CONTENTS**  **BACK**  **FORWARD**

Progress through partnership (Key points): Health & Life Sciences, Page 1

# Progress Through Partnership: 4 Health and Life Sciences



[Contents](#)

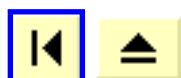


## CONTENTS

[Preface](#)

[Foreword](#)

1. EXECUTIVE SUMMARY	<a href="#">1</a>
2 INTRODUCTION	<a href="#">4</a>
2.1 The importance of the Health and Life Sciences sector	4
2.2 The characteristics of the sector	6
2.3 The panel and its programme of work	9
3. FOUNDATIONS	<a href="#">12</a>
3.1 Benchmarking	12
3.2 Trends and driving forces	20
4. <a href="#">TOPICS</a>	26
4.1 Priority setting	26
4.2 Important issues and opportunities	27
4.3 Barriers to progress	43
5. RECOMMENDATIONS FOR IMPLEMENTATION	<a href="#">45</a>
5.1 Comments on implementation	45
5.2 Actions and initiatives recommended	47
6. CONCLUDING REMARKS	<a href="#">54</a>
7. REFERENCES, ACKNOWLEDGEMENTS, ABBREVIATIONS	<a href="#">56</a>
8. ANNEXES	<a href="#">60</a>
Annex 1 Terms of reference	<a href="#">61</a>
Annex 2 Programme of work	<a href="#">63</a>
Annex 3 Workshops	<a href="#">68</a>
Annex 4 Discussion papers	<a href="#">77</a>
Annex 5 Panels initial 'Hypotheses'	<a href="#">86</a>



[Contents](#)





## Progress Through Partnership: Preface

The Technology Foresight Programme is a major initiative which was announced in the 1993 White Paper 'Realising Our Potential'. The Programme brings together industry, academia and Government to consider how the UK can best take advantage of opportunities to promote wealth creation and enhance our quality of life. The Programme has been driven forward with great energy and enthusiasm by the 15 independent Technology Foresight panels. The Programme has reached out to over 10,000 people.

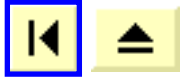


I believe that the current findings from the Technology Foresight Programme will prove invaluable. They will help businesses, academic institutions and policy makers to **Progress Through Partnership**. I know that, encouraged by the Office of Science and Technology, several other organisations are embarking on the Foresight approach. Only by bringing together science and business more effectively will we secure the economic performance necessary to maintain our competitiveness.

The Foresight panels have generated visions of the future which will lead to more informed decision-making in both the public and private sectors. I would like to thank them for their wholehearted devotion to this important mission. We now look forward to a busy and exciting period as the results of Foresight are drawn together and the Foresight process moves forward.

*The Rt Hon David Hunt MBE, MP Cabinet Minister for Science and Chancellor of the Duchy of Lancaster*

# Progress Through Partnership: 4 Health and Life Sciences



[Contents](#)



## FOREWORD

The first UK Technology Foresight programme has come at a time of great promise and change for the health and life sciences. Across the globe, the advances in basic knowledge made over the last two decades are being translated into new treatments for illness, new products, and new industries. Even more exciting, the pace of discovery is accelerating, innovative opportunities are widening, and important new areas of demand are emerging - for instance from the increasing proportion of elderly people in the population.

A biological sciences revolution is under way, the impact of which will be greater than the industrial or atomic revolutions. The opportunities this presents are of particular importance for the prosperity and health of the UK. We have been at the forefront of advances in medical and biological research, and we have developed a strong science-based pharmaceuticals industry. At a time of expanding opportunity - but increasing competition - the challenge for the UK is to consolidate our existing strengths while developing the partnerships, structures, and skills that will underpin scientific and commercial growth into new areas. Increased public and private investment will be vital to support this growth.

In this report we describe the strategic issues and priorities that emerged from an extensive programme of fact-finding and consultation. Personally, and on behalf of the Health and Life Sciences panel, I would like to thank all those who made written submissions, attended workshops, and participated in the Delphi survey. Without their effort, insight, and goodwill, we could not have prepared this report.

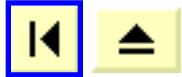
This report is, however, only a first step. The ideas and recommendations which emerged from this exercise will be of value only if they are matched by action, cooperation, and commitment across academia, industry, the health services, medical charities, and government.

*PROFESSOR MARK WJ FERGUSON, Chairman, Health and Life Sciences panel*



[Contents](#)





## 1. EXECUTIVE SUMMARY

### Background

The Health and Life Sciences panel, between April 1994 and January 1995, reviewed long-term trends in science, technology, health care, health related industry, and non-medical applications of the life sciences, and assessed the principal opportunities and challenges presented. The review was based on an intensive programme of fact finding, debate, and consultation. This report describes the methods used, the principal findings, and recommends strategic priorities for public and private sector science and technology in the United Kingdom.

### Findings

The UK has at present an excellent international standing in health and life science research and innovation, though the sector is becoming increasingly competitive. These research strengths underpin industrial success - particularly a strong pharmaceutical industry, and a good development of new biotechnology businesses.

There is a general consensus on the principal trends affecting use of technology in industry and health services:

- ageing populations in the developed world
- opportunities offered by human, animal and plant genome projects and other advances in molecular genetics
- changing healthcare policies and health service organisation
- new patterns of vertical and horizontal integration in health-related industries
- increased importance of information technology and communications in medicine and the life sciences.

Economic opportunities are growing rapidly, driven by a very high rate of scientific and technological advance. The panel urges UK government and industry to expand investment in this key sector.

### Infrastructure

While there is scope for greater cohesiveness and focus in public and private sector research, the highest priority must be to facilitate exploitation and improve the infrastructure for further development. Action is recommended on: improving the university/industry interface; promoting co-operative programmes within the university sector; the fiscal and regulatory environment for new company formation; additional technology incubators; and greater investment in the physical infrastructure for life sciences research in universities.

It will also be important to maintain a strong clinical research base, to underpin development and

evaluation of new products and methods, and to support basic research projects.

## Opportunities for research and exploitation

Priority research areas were chosen to reflect: potential social and economic value; degree of scientific and technical opportunity, potential to exploit in the UK and current research capability in the UK. Action is recommended on the following priority areas (in descending order):

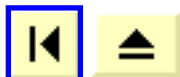
- Integrative biology: research integrating molecular biology and genetics with cell and tissue biology and whole organism studies, to accelerate progress in basic research.
- Neuroscience and the cognitive sciences: research into progressive degenerative disease and non-specific age related cognitive decline.
- Ageing: basic research into ageing and disabling degenerative diseases, coupled with technologies for sustaining reasonable quality of life for the elderly infirm.
- Genetics in risk evaluation and management: understanding the role of genetic risk factors in multifactorial disease, and applications in prevention and treatment.
- Drug creation and delivery: biological, molecular and chemical sciences supporting new classes of therapeutic agents.
- Recombinant technology: research into key metabolic pathways, metabolic engineering, and sciences relevant to biological manufacture of industrial products.
- Diagnostic applications of molecular biology: applying research into disease at genetic, molecular, and cellular levels to develop new generations of diagnostics.
- Immune-manipulation: research into the control of the immune system and applications in specific interventions in inflammatory and immune disease, vaccines, transplants and other areas.
- Medical information technology: developing innovative ways of using information and communication systems to support clinical decisions and practice.

The report recommends specific steps by which these areas might be developed.



[Contents](#)





## 2. INTRODUCTION

### 2.1 THE IMPORTANCE OF THE HEALTH AND LIFE SCIENCES SECTOR

#### The emergence of biology as a dominant science

Biology is the science for the new century. Just as the physical sciences shaped much of the progress in the early part of this century, so biological sciences will increasingly shape progress in the next. The cloning of genes and their modification has a potential economic and social impact greater than that arising from the atomic and industrial revolutions. Health care industries and individuals alike will benefit from advances in understanding the biological basis of human and animal health and disease. Entirely new industrial sectors will develop from applications in the diagnosis of environmental pollutants, the genetic modification of plants and animals for manufacture, agriculture, and bioremediation, and in managing the global environment. Biological sciences will improve health and create substantial sustainable wealth.

#### Technical opportunity

New powerful and pervasive life science research techniques in, for example, molecular biology, cell biology, genetics, and advanced instrumentation have made tractable biological questions which would have been impossible only a few years ago - such as the functioning of the brain, the immune system, development, or ageing. Scientific advances are also improving technology for molecular and bioprocess design, and the productivity and versatility of production of food, chemicals and materials in biological systems. Opportunities will broaden further as the highly successful human, plant and animal genome projects near completion early in the next century, and with developments in IT applications in medicine and life sciences.

#### Economic and social importance

The Health and Life Sciences sector offers outstanding scope for major economic expansion through application of generic biological technologies in new areas, and to increase productivity of existing industries, across a range including all health care products and cosmetics, food and nutrition, chemical synthesis and manufacture, agriculture, non-food agricultural products, and environment management. The economic opportunity has been recognised worldwide - for instance in the White Paper on Growth, Competitiveness, and Employment by the Commission of the European Community [1], and in the technology policy of the USA [2]. We are entering the period when nations reap the dividends of advances in the health and life sciences.

Needs and markets are expanding. Life sciences will provide valuable tools for responding to global environmental challenges. Solutions to past problems may come from genetically modified micro-organisms and plants employed in bioremediation, whilst biological manufacture in plants and animals may provide economic and environment-friendly alternatives to current methods. At the same time a

global population explosion is in train, whilst developed countries will experience increasing numbers of aged and dependent citizens. Social changes will shift the balance of wealth, poverty, and power. Maintaining good public health in the face of these challenges is central to quality of life and prosperity: to healthy development and education; and to physical and mental capability for productive work leisure, independence and self-esteem.

### Realising our potential: the United Kingdom's position

The health and life sciences sector enjoys some of the strongest academic/ industrial linkages: basic research has direct relevance to industrial exploitation, and a strong science base underpins the growth and innovation of our strong pharmaceutical industries and is key to the development of new biotechnology and instrumentation businesses. The expanding opportunities in the sector and our recognised scientific strengths present the UK with outstanding opportunities. There are also challenges. Recognition of the importance of the sector in the USA, EC and Japan is accompanied by increased investment and competition - Japan in particular is rapidly developing world class scientific and technical ability. The field is very fast moving, and if the UK allows its position to weaken, re-entry costs will be high and opportunities permanently lost.

The panel urges UK government and industry to increase investment in the health and life sciences sector, to develop basic research infrastructure and facilitate exploitation, and to invest in world class R&D in strategic priority areas.

### Public interest

It is clear from past experience - the USA's space programme for instance - that major scientific endeavours, if properly constructed and managed, have the capability to capture the imagination of school children and the general public, spawning a number of tangible and intangible benefits, including greater interest in science and science training. We are in urgent need of a major new science flagship. Health and the life sciences already enjoy strong public interest: after sport, documentaries on medicine and the life sciences have the highest TV audience appeal; public interest is also evidenced by the strength of the medical research charities. We believe that a programme in the life sciences (eg understanding ageing, development, or the workings of the brain) could serve as just such a flagship to stimulate general scientific interest - nothing could be more appropriate for a millennium project.

## 2.2 THE CHARACTERISTICS OF THE SECTOR

### Scope

The sector encompasses all businesses, services and technologies relevant to healthcare, and closely linked activities in other sectors (eg biotechnology) which share a common scientific base. Health-related industries and activities include:

pharmaceuticals (both prescription-only, and over-the-counter medicines); diagnostics; medical instruments and general equipment and supplies; novel medical procedures; knowledge and techniques to support the management of health care; health promotion and nutrition; and environmental toxicology.

Applications of the life sciences which are not directly related to health, but share a common scientific base include:

biotechnology in manufacturing; non-medical applications of biological sensors; methods for production of improved plant and animal strains; non-food crops.

The Health and Life Sciences sector has important overlaps with other Foresight sectors:

Agriculture, Natural Resources and Environment

Chemicals

Food and Drink

IT and Electronics

Leisure and Learning

Materials

We have not attempted to address: food and drink except as they relate to health promotion; non-medical environmental issues; and applications of biotechnology in bioremediation and mineral extraction. While the life sciences underpin these areas, they are better dealt with by other panels. We did not address accident prevention, as this should be a generic theme in good design, and of equal concern to all sector panels.

Subsectors: scale and characteristics

The sector is dominated by medical applications of the life sciences. Health related industries are major employers, consumers, and contributors to the economy in all developed nations. Health care systems typically consume between six and nine percent of gross domestic product (excluding the USA, at 12.5 per cent). Spend has risen rapidly over the last two decades - in the UK, USA, France, and Italy spend doubled in real terms between 1980 and 1990, as a result of the changing needs and expectations of ageing, affluent populations, uptake of new technology, or due to ineffectiveness of systems. Policies have been dominated by attempts at cost containment, using methods such as shifting costs closer to the user, increasing competition, limiting activity or spend, or improving use of resources[3].

Closely related to healthcare are the pharmaceutical and medical device/diagnostics industries, with global sales of £130 billion and £47 billion respectively in 1991[3, 4]. Despite cost-containment measures, worldwide markets show steady growth, if more modest than formerly. The pharmaceutical industry is fairly fragmented, with no company accounting for more than four per cent of the world market. Fourteen of the top thirty companies are European or part-European, with the remainder based in the USA or Japan. It is highly research intensive - with business success determined primarily by the ability to innovate and supply new products. The medical devices and diagnostics industry is less fragmented in that a few large manufacturers account for a high proportion of sales, particularly in the most advanced instruments and devices - though with large numbers of very small businesses in the diagnostics sector, and at the "low-tech" end of the medical devices market[3]. Here the USA is particularly strong, and accounts for two-thirds of world production.

The biotechnology sector, as commonly defined, comprises a very diverse set of innovative enterprises. Some are medically oriented, developing novel therapeutics and diagnostics based on advances in genetic modification, and molecular and cell biology from the 1970s onwards. Others are concerned with applying the understanding of living organisms and biological components to create new industrial products and processes as diverse as biological pest control, biological catalysts, improved animal strains, or non-food crops. For clarity, we have generally referred to the former area as "medical biotechnology", though we recognise that there are important overlaps, in terms both of applications and underpinning science.

Taken together, there are over 1500 companies worldwide, of which over 265 are publicly quoted.

More than 70 per cent of these are based in the USA [5], with about 25 per cent in Europe [6]. Of these the largest number are in the UK. The majority of enterprises are in medical biotechnology, in the therapeutics (42 per cent) or diagnostic sectors (26 per cent). Agricultural biotechnology accounts for 15 per cent of businesses, supply of intermediates or reagents for 8 per cent, and chemical and environmental processes, and service companies, account for the remainder. Most of the companies were formed during the 1980s and are small, with an average of around 100 employees [5,6]. In many cases alliances with larger partners are essential to support the commercialisation of products and maintain a flow of capital. For the large established companies, partnership with small biotechnology companies is often seen as the most effective way of introducing innovative product types and new management styles.

Innovation in health and life sciences industries involves stronger links between basic academic research and businesses than in other high-technologies such as electronics [7,8]. The complexity and diversity of biological systems means that basic research has a relevance and immediacy rare in other sectors: the processes discovered in basic medical research are often of immediate relevance as potential diagnostic and therapeutic targets. New, innovative biotechnology and bioengineering businesses tend to cluster around academic centres of excellence, and maintain close links with academic research [7,8]. For both small and large businesses, transfer of key individuals from academia is a common way of acquiring new competences.

Another special feature of the life sciences sector worldwide is the element of charitable funding of R&D, which reflects strong public interest in health issues. In the UK medical charities spend over £300 million each year on basic and applied research. Most are disease-specific charities with close associations to the needs of sufferers, which provides a research focus that complements public and industrial R&D: charities have a strong interest in translating knowledge into practical benefits, whether through release of findings into the public domain, or through product/service development by industry or health services. In this way charities make a significant contribution to the overall strengths of the UK in biomedical research. Much of their spend is closely integrated with universities and medical schools, and, in turn, charity R&D benefits from the strengths of the science base and HEI infrastructure.

## 2.3 THE PANEL AND ITS PROGRAMME OF WORK

The Health and Life Sciences panel was formed in April 1994, and met for the first time the following month. The panel's terms of reference and its schedule of work over the following nine months are recorded in detail in Annexes 1 and 2. The panel began its work by developing ideas on the trends and driving forces that will effect major, long-term changes in technologies, products and services over the next 10 to 20 years. Debate within the panel was supported by reference to previous work in formal consultation with colleagues, and a small opinion survey. There was a high degree of consistency in the views we obtained from all sources. The vision of the main trends that emerged was generally endorsed during the panel's later consultation work and forms the basis of section 3.2 of this report.

The panel did not develop formal scenarios, due to time constraints. Instead, it developed "Hypotheses" (see Annex 5, and Companion Paper C) on how groups of related trends and constraints might interact to drive change. We drew, to a limited extent, on scenarios prepared for other exercises.

Consultation had a central place in the programme of work. It was undertaken not only to test panel ideas and refine views, but also to promote debate and general exchange of ideas among the academic, business, and health care communities. To ensure the widest possible representation of views, the panel carried out a major postal consultation exercise in parallel with the Delphi survey and

workshop programme prescribed in the terms of reference. The consultation exercise invited views from a broad range of trade associations, professional bodies, charities, research organisations and individuals. It was based on an open-ended questionnaire and the set of "Hypotheses". Results are presented in Companion Paper C.

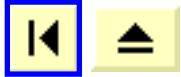
The Delphi survey had a high profile throughout the planning and execution of the Foresight programme, but the survey results proved no more useful than those from the other methods of consultation. The results are broadly consistent with those from other methods, though usually, despite the quantitative nature of the survey, only quite general inferences can be drawn. The interpretation of the results, and their consistency with other sources of opinion and with the panel's priorities, are discussed further in Companion paper B. A report on the panel's workshops is presented in Annex 3.

The panel primarily used existing studies to "benchmark" the current strengths and weaknesses of UK industry and research against other countries. These were complemented by a commissioned bibliometric survey of research outputs for a range of disciplines in the UK and 11 other countries, and a review of R&D investment patterns. Methods and results are described in Companion Paper A.

Priority areas were identified using the criteria suggested by the Foresight Steering Group (Annex 2). Short-lists of important areas were prepared, based on probable long-term needs, scientific and technical opportunities, and social and economic importance worldwide, and drawing on the postal consultation exercise, workshops, and Delphi. The short-list was then narrowed through detailed discussion of:

- social and economic value
- degree of scientific and technical opportunity
- potential to exploit in the UK
- current scientific and technical capability in the UK

The gap between the current UK position and that desirable; the changes that might place the UK in a better position; and the value, feasibility, cost, and timing of these changes were taken into account in the prioritisation process.



## 3. FOUNDATIONS

### 3.1 BENCHMARKING

#### The science base

Basic medical and biological science is one of the UK's greatest strengths. The UK's research output in these areas is relatively large, and about 10 per cent of UK graduate output, and 30 per cent of doctorates, are in medicine, dentistry and the life sciences [9]. The UK has an excellent record in the most important and rapidly developing disciplines, as evidenced by a high share of the most cited publications in the life sciences [9], and international recognition of excellence through Nobel prizes and other awards. On a broader scale, medicine and the life sciences are one of the stronger areas across western Europe. A recent report [10] using patent-based measures of innovation found that drugs/medicines and biotechnology (along with advanced materials, polymers, and chemicals) are the sectors in which the EC has best kept pace with Japan and the USA over the last decade.

The panel used two approaches to review the UK's relative position in a range of disciplines in the health and life sciences. Firstly, we commissioned a bibliometric survey of twelve OECD countries with a high profile in the sector, combining measures of output and quality (based on the quality of the journal). The full survey results are available as Companion paper A. The survey could not address all disciplines, and most areas of clinical research were excluded, as these had been covered in a recent study [11].

The survey results confirm the UK's strong overall position in the life sciences, with a position second only to the USA in many disciplines. Compared to other countries of similar size, the UK also has a good presence across a broad range of areas, and the gap between the stronger and weaker disciplines is not great. Figure 1 (a) shows UK share of world output, weighted by quality, for the disciplines surveyed.

The survey reveals an increasingly competitive sector (see Figure 1 (b)), with output expanding in almost all countries, especially in fast-moving disciplines such as genetics. It is also noteworthy that when output is set against population, the largest countries are only average performers, with Sweden, Switzerland and Canada the most productive.

Judged against the UK's average activity in all disciplines, we have a particularly strong presence in pharmacology, immunology, genetics, psychology and psychiatry, and veterinary science. The UK has an above-average presence in all the smaller disciplines we surveyed - development, nutrition, tropical medicine, ageing, and informatics (biological and clinical) - with a particularly strong presence in tropical medicine. The UK has a slightly smaller presence in biochemistry/molecular biology (using a broad definition), cardiovascular research, and cell biology.

These measures of performance across a discipline are based on overall scale of effort and averaged

quality. They must be interpreted with caution, as they will not necessarily reflect performance in the most rapidly moving or important areas within the discipline, or indicate the presence (or absence) of world class centres of excellence. Therefore, as a second, complementary approach, we drew on expert views from key funding bodies and trade associations, from the Delphi survey and workshops, and from previous subjective and quantitative studies. There is widespread agreement that the UK has a world class position in genetics, genome research, transgenic technologies, and areas of molecular biology including, macromolecular structure and function, and protein engineering. This is supported by quantitative studies [25] which rank UK centres of excellence among the best worldwide in genetics and molecular biology. The UK is also consistently rated as world class in immunology, development, psychology and imaging, as well as many smaller disciplines such as cell signalling.

## Clinical research

The structure of the National Health Service, especially the relative equality of treatment, and degree of central control of the delivery of care, offers special opportunities for the development and evaluation of innovative procedures and technologies.

The UK has a strong presence in academic clinical research, and accounts for 11.8 per cent of world publications. UK publications have above average citation rates, especially in areas such as surgery, neurology, orthopaedics, reproduction, and medical technology [11]. The UK also has a strong position in academic public health and health services research, and epidemiology, and is seen by industry as providing a good base for high quality clinical research / trials for (potential) product licensing. However, those we consulted in the research community felt that the UK's leadership in academic clinical research has declined in recent years. Bibliometric indicators point to either a decline in quality, or an increase in the competitiveness of the field: relative frequency of citation is now 21 per cent above average, but was 33 per cent above average between 1981 and 1985 [11].

## Pharmaceuticals

The UK pharmaceutical industry has a well documented record of economic success. The UK accounts for about 6 per cent of world sales, and is the fourth largest exporter of pharmaceuticals, after Germany, and (narrowly) the USA and Switzerland. The sector is one of the largest contributors to the UK balance of payments [4, 12]. The industry has a good record in innovation - six of the world's top 20 medicines were developed here, and there is a high level of R&D investment by global pharmaceutical industry standards. Over the last decade productivity gains have exceeded those of EC rivals, though the industry still lags behind the USA and Japan in terms of output per employee [DTI indicators]. Success relies heavily on the strong domestic science base, though it also benefits from the network of international communications that characterises both the academic life sciences community and the pharmaceutical industry. Direct employment in the UK is 80,000. The sector includes nearly forty "biopharmaceutical" companies. Most are less than ten years old, small (most have turnovers below £5 million) and with, as yet, little income from sales [13].

## Medical instruments, diagnostics and devices

The UK position in the biomedical equipment market is weaker: UK manufacturers are estimated to have about 3 per cent (£1,400 million) of the world market and only 25 per cent of the domestic market, though both market share and productivity have increased over the last five years [3, DTI indicators]. Performance varies across the sector. In "low-technology" products (care and rehabilitation equipment, dental equipment) the UK has a growing trade surplus, but a growing deficit in "high-

technology"products (endoscopes, MRI, intensive care monitors) [14, 3]. There are anestimated 400 companies in the sector, employing 25,000, though most are small, and half have less than 10 employees. Many SMEs in this sector do not enjoy the close linkages with current academic research found in biotechnology, or pharmaceuticals, and some lack good links with medical practitioners and users.

In the in vitro diagnostics market (equipment, kits, and disposables) the position is somewhat better, and domestic manufacturers have 50 per cent of the home market. The UK has a good record of innovation in biological diagnostic techniques (antibody technology, biosensors, DNA fingerprinting) and there are over forty biotechnology based diagnostics businesses. Though most are very small, product lead times are shorter than for bio-pharmaceuticals, and businesses are more mature, with most revenue coming from product sales, which were around £100 million in 1992/3 [13], with good gross profit margins.

## Biotechnology

To date, the EC has tended to lag behind the USA in developing biotechnology based businesses. The reasons - investment, regulation, infrastructure and organisational issues - are well documented [13, 15]. For the longer term, though, biotechnology will be particularly important for European competitiveness through its impact on the agriculture, chemicals, food and medical sectors - which account for more jobs in the EC than in the USA or Japan. Biotechnology-derived products have the potential to take eight per cent (average) of these markets by the year 2000 [15].

Within Europe, the UK has the best record of new company development (one third of the EC total), and early measures of development suggest performance of individual companies will be able to match that in the USA [13]. The UK also has a good record of innovation in molecular biology and genetics, and by 199() had five of the 35 most highly cited patent families (ie the top one per cent of patents) in recombinant DNA technology [26]. The UK position is attributable in part to the strengths of the science base, and to the regulatory environment.

As well as 70-80 biotechnology companies in pharmaceuticals and diagnostics, there are a further 22 agricultural businesses, and over 60 companies manufacturing reagents for the industry. Agricultural biotechnology has tended to develop relatively slowly - in the UK and elsewhere - partly due to natural limits on the pace of product development and testing. Biotechnology R&D is also pursued, on a large scale, within major companies in the UK pharmaceuticals and agrochemicals sectors. The growth of this activity is less well documented, though one estimate classed 33 per cent of current R&D spend within SmithKline Beecham as biotechnology [13].

## Health services in the UK.

Health services are by far the largest economic sub-sector, accounting for expenditure of £38 billion (NHS and private combined) in 1992 [16]. The NHS alone employs 1,200,000 (1991). There are no suitable ways of comparing the performance or productivity of UK health services with those elsewhere, or of measuring its contribution to the real wealth of the country.

Similarly, it is difficult to assess the contribution of national research to the performance of health services. However, although medical knowledge gained in one country could in theory be freely taken up wherever relevant, in practice, research appears to be of greatest value to the country in which it is performed. This is certainly true for evaluative and operational research. Close involvement in research

will affect the quality of clinical teaching and practice, and the rate at which new techniques are developed and adopted. In turn, the UK's ability to "export" medical training is based on research reputation, and some of those we consulted stressed the value of training overseas clinicians and scientists in paving the way for healthcare industry exports.

National Health Service structure and policies shape the domestic market for new technology, and influence the UK's clinical research capability and opportunities for collaborative technology development:

- the NHS is the one of the world's largest unified health care organisations. Standardisation (eg. the use of a single NHS number) facilitates long-term monitoring, and treatment follow-up and evaluation, and there are well established, high standards for clinical trials practice.
- UK total health expenditure per head is well below OECD and European averages, with particularly low levels of spend on capital medical equipment and diagnostics. Spend on prescription and over-the-counter medicines is also relatively low. This small home market can be an advantage for smaller producers without global reach, though the emphasis on effectiveness, and the discriminating nature of the market can also confer some benefits.

## Investment in R&D

Table 1 shows the pattern of R&D investment in the UK in 1992. The health and life sciences sector, in its broadest definition (ie including food and agriculture R&D) accounted for about £3.5 billion, or 27 per cent of all R&D in the UK. Government spending accounts for 34 per cent of this, covering basic research (eg in Universities and Research Council establishments), applied research, and developmental research (eg to support health service activities).

International comparisons are difficult, and cannot be made with any precision. Such comparisons as are possible generally emphasise the importance of the sector in the UK and the strength of industrial R&D. Estimates of government spend on health sciences in OECD countries vary between 12 (eg Australia) and 19 per cent (eg Sweden) of total government R&D. Since health sciences account for the bulk of life sciences R&D, the UK with £1.2 billion investment in health and life sciences (combined) out of total government spend of £5.5 billion (22 per cent), would be in the upper half of this range. The UK also has one of the highest ratios of industrial investment (mainly pharmaceutical) to government investment among western economies, with a ratio of around 1.4:1. The ratio in the USA is estimated at 0.9: 1 (health sciences only). In Japan the ratio is estimated as 5:1, though in all sectors ratios of industry: government R&D investment are much higher in Japan. These comparisons, and the limits on their interpretation, are discussed further in Companion Paper A.

Table 1 - R & D investment in Health and Life Sciences in the UK

Source	£Bn in 1992	% of sector R&D
<b>Government</b>	1.2	34%
<b>Breakdown</b>		
General health & life sciences	0.3	
Bio-engineering, medicines, nutrition, food hygiene, other medical	0.1	
Animal products, vet medicine, fish, crops, forestry, food technology, other agricultural	0.2	

UFC/HEFC funds (Pro rata)	0.3	
National Health Service R & D (Estimate)	0.3	
<b>Industry</b>	1.8	51%
Breakdown		
Pharmaceuticals and medical chemicals	1.5	
Other healthcare	0.1	
Food, Drink, Tobacco	0.2	
Agriculture & Agrochemicals	N/A	
<b>Private sector no-profit</b>	0.3	9%
(Medical Research Charities)		
<b>Other (estimated)</b>	0.2	6%
International funding agencies	0.1	
Higher education endowments etc	0.1	
<b>Total</b>	3.5	100%
(UK spend on all R & D	13.0)	

## Sources

*UK government spend is based on Eurostar's NABS classification, and information from government departments. Industry spend from Central Statistical Office. Private non-profit spend from Association of Medical Research Charities.*

*Further details in companion paper A*

## 3.2 TRENDS AND DRIVING FORCES

### Health needs

Compared with most services and products, the demand for health care changes slowly. The best documented trend in health needs is the ageing of populations in developed countries. In the UK the proportion of the population over 65 was 11.7 per cent in 1961, is now 15.7 per cent and will reach 17.5 per cent by 2015 [17]. This will inevitably increase the prevalence of disease and disability, particularly somatic degenerative diseases (cataracts, osteoarthritis etc), neoplasms, cardiovascular disease, and neurodegenerative disorders. Figure 2 shows estimates of future costs of acute, general practice, and long-term care needs of the elderly, extrapolated from current needs - with the largest and most sustained increase being in long-term care. The picture is far from simple: future medical need may be affected by further increases in life expectancy, or changing health and lifestyles among those currently middle aged. The impact of that need on services and products may be magnified by attitudes to elderly people, their increasing political power, attitudes to care by relatives, increased affluence of some elderly subgroups, and technical opportunity. Alternatively, it may be diminished by resource limitations or changes in welfare structure.

Long-term changes in economy and social structure, while much more difficult to foresee, may be of even greater impact. In the most stable, affluent societies, lifestyle, working environment, family, wealth and social disparity still have clear effects on health. The effects of unemployment, poverty, overcrowding, drug and alcohol abuse, and violence will become much more marked if current prosperity, social equality and cohesiveness, and human environments cannot be sustained over coming decades.

Cultural change is another major variable: public understanding of science and medicine, and attitudes to individual responsibility determine, to a large extent, the effectiveness of preventive medicine. We are already seeing the development of more literate, aware "health consumers", with high expectations. If this trend continues, it may have positive effects on the quality and effectiveness of care and communication, and the transparency of decision making. However, it could also mean that inequalities in wealth, education, and attitude are more rapidly translated into individual and regional variations in care, and could divert resources into treatments and types of service focused on the subjective well-being of the patient rather than measurable health benefits.

In developed countries, a high proportion of hospital admissions, premature death and disability is due to accidents and trauma. Better treatment is important, and feasible, to ensure return to a healthy productive life, but the most obvious need is for more effective preventive and deterrent measures, though here too cultural, political and economic factors make accurate predictions impossible.

Worldwide, population growth will be concentrated in Africa, Asia, and South America, and the proportion living outside the (current) developed world will reach 83 per cent by 2020. The health needs of the poorest countries will probably be dictated by congestion, nutrition, sanitation, and environmental degradation: infection will remain a major killer and the main needs will be for basic preventive measures such as clean water, health education, and vaccination. Among the more prosperous developing countries (eg in south-east Asia) median age of death will increase, and diseases of affluence and age will mix with problems specific to culture, climate and infrastructure. Markets for high-cost, high-benefit treatments will certainly broaden.

Some needs cannot be predicted or extrapolated from current trends. In the last four decades we have had to respond to major new (or re-emergent) infectious, environmental, and iatrogenic diseases. With greater population density and mobility, environmental degradation and increasing antibiotic resistance, we must assume new threats will continue to emerge.

### Trends in health policies and health service organisation

There are a number of emerging trends which are common to developed countries throughout the world, which are likely to dominate health care for the next ten or twenty years:

- cost-containment strategies, worldwide, are placing increasing emphasis on evaluation of procedures and technologies, improved resource allocation, health promotion and the prevention and early detection of disease [3]. Improved measures of cost/benefit will create some new markets while eroding old ones, while strategies involving shared costs or co-payments (by patients/insurers), and those based on encouraging competition, will change the way demand for new technologies evolves, and the way it is met.
- a narrowing of the role of hospitals, with shorter-stay surgery, more specialist consultation outside the hospital environment, and greater use of separate centres for convalescent, geriatric, and terminally ill patients. An increasing proportion of the most specialised services are being provided off-site. Such decentralisation has increased acutely the need for effective communication and information transfer systems.
- the desire for care close to home, together with greater emphasis on prevention and shorter hospital stays, is increasing the importance of primary health care, and the demand for technologies and communication systems that enhance the capability (eg in advanced diagnostics, telemedicine) of primary care organisations.
- the distribution of expertise and information seems to be gradually changing, with less

dependence on medically qualified individuals and greater emphasis on teamwork, and with expanding roles for different professional groups. Moves towards protocol based care will contribute to re-defining the role of the medical professions.

- the change in the population age structure, and increased survival after acute but disabling conditions is increasing demand for rehabilitation aids and aids for daily living. At the same time improved ability to measure the social and economic burden of disease looks likely to lead to greater emphasis on chronic disability at all stages of life.

These trends are already evident: the key uncertainties are the speed and degree of progression, and the interaction of these trends with:

- political change and social / cultural change, nationally and internationally especially the degree to which society and individuals value health care relative to other areas of public or private expenditure
- changes in economic growth and distribution of wealth
- the rate of scientific advance, and the degree to which new technologies deliver substantially improved cost-benefit ratios for overall disease management.

## Environment

Growing awareness and imminence of global environmental problems is likely to bring increasingly tough action from governments to reduce consumption of energy and materials, and increase recycling. In the long term, commodity costs, patterns of transport, mobility, housing, automation and employment may change, with some positive and some adverse effects on population health. Healthcare industries will be affected too, though with relatively low physical inputs and high added value, the effects might be less severe than in other sectors. There might be increased demand for crops able to maintain yield with less use of "artificial" fertilisers, for production of complex biochemicals, materials, and fuels from renewable resources, and technologies for environmental monitoring and bioremediation. However, the rate of change is not certain and political pressure for "green" legislation or incentives is often linked to distrust of technologies based on genetic modification.

## Business trends

The pharmaceutical industry has begun to segment into companies with strategies that differ in degrees of horizontal and vertical integration. The last two years have seen several of the largest companies take over, or ally with, pharmaceutical benefit management firms in the USA, or other health management businesses. Particularly in the USA, the trend may produce new types of healthcare company, with portfolios encompassing insurance, care, health education, and prevention (eg nutritional products), diagnosis, treatment and rehabilitation. Prescription drugs can now be seen as only one part of the product range, with integration not only providing a means of advancing sales, but also ensuring that, within the overall costs of disease management, drug price is not subjected to undue pressure. A further benefit is access to high quality information on disease prevalence, treatments, and outcomes to inform development strategies and evaluation.

Pharmaceutical R&D portfolios are becoming more tightly focused, partly to contain costs, and partly because success increasingly depends on major innovative advances rather than general incremental development. At the same time, larger businesses are looking to alliances with small biotechnology companies, or groups in academia, to complement in-house R&D and improve the rate of

innovation, particularly at a time of accelerating advances in biological knowledge and the development of new technologies.

Within the biotechnology industry, particularly in the USA, initial expectations proved too high in some cases, and investment is now harder to obtain than in the 1980s. Nevertheless, while there has been retrenchment and re-structuring, we have not seen the large increases in company failures and consolidation that some predicted [5]. The slower, but sustained, development experienced in Europe may give a more stable investment climate.

## Technological trends

On a broad scale, we expect that the advances made over the last three decades in the science of molecular genetics and in information technology will have the greatest effects on the technologies and methods of health care and other life science based industries over the coming decades.

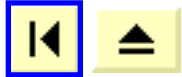
The science of molecular genetics has greatly accelerated our rate of acquisition of knowledge of human, animal and plant biology - not least through genome analysis - and forms the basis for much of the biotechnology industry and current trail-blazing work on gene therapy, early detection of cancer, pathogen characterisation, and pre-natal diagnosis of defects. It is also revealing new therapeutic targets and approaches for novel drug creation. In the longer term, understanding the inherited factors predisposing to common illnesses such as heart disease, and their interaction with lifestyle and environment, may revolutionise medicine, allowing individual measures of risk tailored prevention plans and better informed choice of treatments.

The importance of information technology and communications in medicine is well recognised, but here too, current applications give only a foretaste of what may be possible as the performance and price of hardware and software continue to improve. Advanced computer-based models are already essential research tools in genetics and molecular biology, and are likely to be of increasing importance in other areas, in maintaining the speed and productivity of research in increasingly complex systems. These trends were explored in greater detail in the panel's initial consultation paper, which is included as Annex 5.



[Contents](#)





## 4. TOPICS

### 4.1 PRIORITY SETTING

Before presenting our conclusions on priority areas, it is important to describe the context within which they should be interpreted, and the process by which they were produced.

The panel has concentrated on strategically important areas where change is needed. Areas which are already widely recognised as strategically important and which are being developed accordingly are not discussed at length. We have assumed that the initiatives and programmes that will stem from the Foresight programme will be superimposed upon a publicly funded science base in which a reasonable research presence is maintained across a diversity of academic disciplines. Several of the priorities are "generic" sciences and technologies with multiple benefits in disparate areas, which will complement this diversity.

We have not identified areas in which to reduce public sector support, for two reasons. Firstly, the biological sciences are in an exponential phase of growth in knowledge and opportunity, and the targets at which we will direct our new fundabilities are in many cases still emerging. At this stage there is advantage in diversity, and we could not recommend wholesale withdrawal from entire areas. Such reductions in funding as are needed can be done effectively on a case by case basis through the element of competition within response-mode funding, in a context set by the balance between strategy-led and blue-skies funding. Secondly, the information needed to identify unimportant areas is in any case greater than we could acquire in the limited time available.

The priority areas identified are viewed mainly from a UK perspective, matching global opportunities and needs against UK scientific and industrial strengths and abilities. We have not tried to develop strategy from a European Community viewpoint, though in Section 5 we highlight areas where implementation could have an EC dimension.

In Sections 4.2 and 5.2, the issues, opportunities and recommendations are presented in descending priority order.

### 4.2 IMPORTANT ISSUES AND OPPORTUNITIES

Infrastructure for the development and exploitation of the life sciences

The UK has internationally recognised strengths in the life sciences and biomedical research, areas which are of growing economic and social importance, and are beginning to attract increased attention from industrially influential countries such as Japan and Germany. The UK must now build on its special position in the life sciences, and to do so successfully we must give a high priority to ensuring that the infrastructure for further development and exploitation matches the characteristics of the sector. The five most important areas are:

- **New company formation and funding**

In the last five to ten years the numbers of new, life-sciences company start ups in the UK have been reasonably good by European standards. The recent relaxation of London Stock Exchange rules has been particularly beneficial, in providing access to a wider spectrum of investors, and allowing early investors an easier exit route. The replacement of the Business Expansion Scheme with the Enterprise Investment Scheme (EIS) is another welcome recognition of the problem of attracting investment. However, we still lag well behind the USA, and are not yet fully realising the potential offered by our strong academic science base. Obtaining seed capital, and access to early stage venture capital, and mechanisms for flotation, remain problems, and are proving a significant obstacle to the formation and development of new businesses - these factors are discussed in detail in Annex 4 (a) [see also 18]. We recommend further steps to improve the investment environment for new, high-technology companies, by introducing tax credit notes, loosening limits on share sales after flotation, and working towards a European equivalent of NASDAQ (National Association of Security Dealers Automated Quotations USA).

- **The interface between academic research and industry**

Throughout our consultation work we encountered the view that the mechanisms for transferring technology and expertise between academia and industry need further improvement. Despite commendable advances in recent years, university technology transfer groups still find it difficult to deliver the technical and business expertise needed quickly and effectively. Lack of mutual understanding and different cultures present further barriers to effective transfer, particularly as there is still relatively little two-way movement of personnel between academia and industry in the life sciences. LINK and ROPAs have been welcome initiatives in this area, but more rapid change is needed. A particularly worrying development is the increasing tendency of charities to demand intellectual property rights on research they fund in HEIs, despite the fact that full costs are not paid: this may result in patent portfolios from groups of academic scientists being managed by several different organisations, to the detriment of industrial exploitation. In section four we recommend a series of further initiatives to accelerate the development of a better interface.

- **Co-operative programmes within the university sector**

We believe that the UK's efforts in academic life sciences research are too finely divided to take full advantage of the opportunities emerging. There is a growing need to carry out large collaborative studies, for instance to combine expertise in a number of disciplines (genetic, biochemical, physiological etc) to address basic research questions, or to study diet, lifestyle and medical interventions in sufficient depth to provide authoritative advice. The increasingly competitive nature of the area internationally accentuates the need for collaboration. At present, not only are resources divided among a large number of centres, but also funding schemes tend to promote competition rather than co-operation. The problem is in part addressed by the HEFCs' selectivity exercises, which concentrate resources in centres of excellence. However, this scheme itself tends to promote counterproductive competition between the best university groupings, to the overall detriment of the UK's position. We therefore recommend assessment and funding schemes which provide incentives to form multi-centre consortia linking centres of excellence.

- **Technology incubators**

Technology incubators are centres, usually linked to an academic centre of excellence, which facilitate

new company formation and collaborative liaisons between academia and industry. Incubators emphasise proactive management, and provision of high quality shared services, in order to: lower entry thresholds; provide access to higher quality business and technical expertise; reduce early failures; reduce risk for investors; and develop scientific, business, and investment networks. Their role in providing low cost short-term space and services is also important. Incubators have been effective in these roles in the USA [19], and several have already been developed in the UK. Their role contrasts with the experience of science parks in the UK, which tend to be passively managed, and are no more effective than the average in nurturing new business, or in linking with academic strengths [20]. We recommend additional investment in technology incubators.

- **The physical infrastructure for life sciences research in universities**

There has been a rapid expansion of technical possibilities in the life sciences over recent years, with the result that much higher levels of capital investment are needed to maintain the productivity, competitiveness and safety of academic research in the UK. For instance, most laboratory space available for research in UK universities is not suitable for safe use of recombinant techniques. Although concentration of resources in centres of excellence is essential, not enough of the top centres have the state of the art research equipment they need to compete with groups overseas, or to form worthwhile collaborations with industrial R&D. Furthermore, low capital and recurrent funding means that current UK life sciences graduates, who will provide the base for future industrial and academic development, have inadequate practical training using state of the art techniques. The pharmaceutical industry has already highlighted the need to improve graduate skills, the university infrastructure, and the competitiveness of UK basic research [21, 22]. One respondent to our consultation paper commented "many students are trained on equipment that is also on display in the Science Museum".

HEFCs have not yet adequately recognised the tremendous shift within the life sciences towards work with intensive capital and running costs, and the greater pace of progress needed to remain internationally competitive. There is a particular danger that the UK will miss out on emerging opportunities in laboratory automation and advanced laboratory IT systems. This lack of infrastructural support is exacerbated by the position of the medical research charities. These do not pay the full cost of research, yet the HEFCs do not adequately fund the universities for unmet infrastructure costs. Lack of adequate HEFC infrastructural funding also increases pressure to increase revenue disproportionately from other sources (eg industry) which discourages collaboration, exploitation, and development of industrial / academic interfaces.

We **recommend** a programme of capital investment in physical infrastructure and capital equipment at high quality research centres. We also **recommend** that a forum should be established to review the issue of charity funding of research.

### Integrative biology

The expansion of the life sciences over the last twenty years, driven by the generic techniques provided by molecular biology, has increased the diversity of disciplines within the field. This has, on the whole, been beneficial, allowing the rapid evolution of new expertise in specialised, innovative, cohesive, communities. Nevertheless, it is timely to address some of the negative consequences of this trend. Specialist disciplines are too often pursued within discrete departments, with insufficient cross-departmental co-operation and contact in either teaching or research, and as the rate of advance in reductionist molecular biology has increased, links with other disciplines have weakened.

The UK is recognised as being expert in molecular genetics, and some areas of molecular biology, and on a global scale has a position second only to that of the USA. Using that expertise in practical applications, whether in medicine, or agricultural biotechnology, often calls for broader, "integrated" understanding of the role of individual gene products in biological systems, at the level of cell, tissue and organ biology, pathology, whole organism physiology and even population interactions. There is a danger that a relative shortage of expertise at these higher levels of complexity, or poor co-operation, may become a limiting factor. This has already been highlighted as a potential problem in the USA [23]. Our consultation work suggests it has been recognised as an issue by UK Universities and Research Councils, though it is not yet given sufficient priority. A particularly important issue is the UK's relatively small presence in cell biology, as expertise in areas such as cell-cell and cell-matrix interactions, motility, adhesion and positional identity will be essential in exploiting our knowledge of molecular and developmental biology, and tackling chronic disease.

It is clear that integrative biology will be essential to reap the rich harvests offered by current work in molecular biology and genome sequencing. Bioinformatics, and transgenic models are important in making use of genetic knowledge: especially important will be development of integrated information systems (combining genetic, structural, functional and taxonomic data) which provide advanced support for investigators. However, there are no universal methods. Understanding complex systems will continue to require collaborative interdisciplinary science, and the UK's capability will be determined by: the breadth of scientific training at post-graduate and post-doctoral levels; development of cross-disciplinary, goal-oriented networks; and individual experience and skill in developing interdisciplinary, complementary research strategies. We recommend that the UK should begin developing stronger integrative expertise within the life sciences base.

## Neuroscience and the cognitive sciences

Neuroscience and the cognitive sciences (in their broadest sense, including memory, thought and perception) offer exceptional long-term scientific promise, and address some of the most pressing problems in human well being and health care. Mental disorders are the single largest category of illness in terms of their cost to health services. Beyond the classic mental disorders, stress and state of mind play a large role in a range of acute and chronic illnesses and conditions manifesting as general, intractable, ill health.

Recent years have seen the application of promising new research techniques to understand brain function, addressing the genetics, molecular and cell biology of the brain, and improved methods of recording activity and high resolution functional imaging. While neuropharmacology has, for several decades, been largely confined to regulation of neuro-transmitter function, new classes of therapy are already emerging. We have already seen the development of potential memory-enhancing agents, and trophic factors which may prove valuable in alleviating degenerative disease. Beyond pharmaceutical treatments, cognitive therapy is proving effective in depression.

The U.K has a good international position in neuroscience research, and is very strong in psychology, psychiatry, and the cognitive sciences. Areas which may be relatively weak include molecular and cellular neurobiology.

Given the ageing populations in the developed world, we see important opportunities in:

- progressive degenerative disease (eg Alzheimer's disease and cerebrovascular disease). There are good prospects for improved understanding of the mechanisms of nerve cell dysfunction,

degeneration and death, offering the possibilities of novel therapies, and diagnostics, and better understanding of risk factors.

- non-specific age-related cognitive decline. Improved understanding at the cellular, cognitive and behavioural levels would be of immense value in caring for ageing populations, and helping achieve the best possible quality of life and level of independence.

In tackling these areas it will be important to improve understanding of the molecular and cellular basis of normal cognitive development, though this area will also become increasingly important in its own right: rapidly changing lifestyles and diet among sub-sectors of the population, and the possibility of early identification of potential problems will increase both need and opportunity.

We would also highlight the research area of psychimmunology. This is concerned with the interaction between brain function, mental state, immunology, and general health. The area is currently small, but will be synergistic with work on immune-manipulation, and may become very important in developing new products and treatments to help maintain good health and address otherwise intractable chronic conditions.

We **recommend** that the UK should give a high priority to strengthening these specific areas of neuroscience, and maintain a strong research presence in broader areas (eg mechanisms of mental illnesses). There is a vast, and growing demand, and the potential for major innovations in health and wealth creation over the next fifteen to thirty years. The UK has the ability to build a strong competitive position in basic science, and is well placed to exploit opportunities for novel pharmaceuticals, diagnostics, psychological treatments and services.

## Age

The ageing populations in the developed world present both enormous challenges - medical and social - and substantial opportunities - not least because the aged will be an increasingly influential consumer market. Research into biological, medical and psychological aspects of ageing, and basic mechanisms, is a relatively small field internationally, but one in which the UK has a strong position. The science effort lags behind the population need, but recent advances in molecular genetics, cell biology and physiology offer new opportunities to address the fundamental processes involved. We **recommend** that the UK should develop ageing research as a national priority.

The prime goal of science and technology should be to improve the quality of life, and provide a reasonable degree of independence for the elderly infirm, rather than to further prolong typical life expectancy. There is already an expanding demand for medical devices, rehabilitation aids / prostheses, and communications systems to assist elderly people and carers. While medical equipment manufacture, as a whole, is not strong in the UK we have a good position in the "lower technology" products and communications systems. We believe there is a need for collaborative projects which draw together industrial engineering and design skills with expertise in medical, sociological, ergonomic and psychological aspects of ageing. Improving the linkage between SMEs and sources of academic expertise (in the life sciences, materials, IT, electronics etc) and users will be especially important. For the longer term, basic and strategic research into the fundamental mechanisms of ageing and the principal disabling degenerative diseases will be essential to underpin development of new therapies.

Basic research into ageing, and development of supporting technologies, must be paralleled by, and integrated with, sociological research and policy research on the role and status of elderly people in

society. Especially important is research into possible future economic roles in employment. We would also highlight the potential importance of ageing in animals and plants for agriculture, and the value of animal and plant research as the basis for comparative studies.

## Genetics in risk evaluation and management

Most current work on genetic disease focuses on relatively simple single-gene disorders. Over the next two decades, as human genome sequencing progresses, there will be increasing opportunity to address the role of genetics in complex multi-factorial diseases such as hypertension or diabetes, where multiple genes may be involved, along with influences from lifestyle, environment, and early development. Identifying the genetic risk factors for major diseases, and the genes associated with good health and immunity, and clarifying the relative importance of these and environmental risk factors could have profound effects on the treatment and prevention of disease. For instance, it might be possible to target sectors of the population at risk or, by individualising risk, to enhance the effectiveness of preventive measures. The knowledge would certainly be useful in developing new treatments, and perhaps in selecting treatment strategies on an individual basis.

It is too early to predict how difficult it might be to dissect out the complex interplay of factors at different stages in life that lead to disease, or how effective individualised risk might be as a public health measure. Clearly, progress will depend on improvements in gene sequencing and diagnostic technology, and on systematic studies addressing genetics, development, lifestyle and environment for large numbers of individuals over a long period. At its most extreme, the development of this "probabilistic medicine" offers potential for major innovations in health and health care delivery over the next twenty or thirty years.

Despite an element of uncertainty, the genetic element in common disease is potentially so important that the UK should begin building a leading-edge position in research in the area. Consumer demand will certainly be strong, and the export potential is high. Important new diagnostic techniques are likely to emerge internationally in the short- to medium-term. For the longer term, we **recommend** the UK should develop the basic, disease-specific, knowledge that will underpin applications in medicine, health promotion, nutrition (see also the report of the Food & Drink panel), pharmaceuticals, diagnostics, and other healthcare businesses; and to explore sociological, ethical and practical issues in the use of this knowledge, building on current strengths in molecular genetics, epidemiology, and the ability of the NHS to support large scale population studies. It will be especially important to ensure that appropriate systems to handle information about gene sequence, polymorphisms, phenotypes and health are developed in parallel with the research.

## Drug creation and delivery

The strategic importance of the UK pharmaceutical industry is beyond doubt. The next ten to twenty years are likely to see a broadening of scientific opportunity, combined with ever tighter research portfolios and budgets. At the same time, the progress of genome mapping and sequencing, and better understanding of integrated biological systems - and pathological processes - at a molecular and cellular level will offer new knowledge of possible targets (receptors, enzymes, genes and other entities) for intervention. Many of these new targets will call for new classes of drug, created using new and more efficient approaches, and novel delivery methods.

Innovative drug discovery, worldwide, will depend on expertise in:

- molecular diversity: understanding the structure and properties of novel classes of molecule, and skill in identification, synthesis, and use of natural source materials;
- molecular recognition: understanding the structure and behaviour of key receptor sites and enzymes and their interaction ligands (natural or artificial); methods of modelling and predicting interactions;
- drug delivery and gene delivery;
- technologies for improving the speed and efficiency of screening: these could include automated analysis, or robotic systems with nano-litre handling capabilities.

While all these areas are undoubtedly important, we note that the UK's current expertise in automation and robotics lags well behind that of the USA, and the benefits to the UK of focusing on this area are less certain.

The UK already has leading edge expertise in some of the important emerging technologies, such as peptomimetic drugs, and some areas of molecular modelling (see, for example Delphi topic 21). There are also several groups researching methods for gene therapy. Nevertheless, there is a need to widen the base of fundamental research and to invest more in undergraduate and post-graduate education, and ensure training effectively brings together the new molecular biology based disciplines with established expertise (eg in chemistry). We **recommend** the UK should strengthen its competitive position in the research, technology, and training relevant to molecular diversity and recognition in drug creation, and drug or gene delivery.

We also highlight the emerging opportunities in pharmacogenetics. Improved understanding of the genetic factors in disease, and in the beneficial (or harmful) effects of drugs may allow choice of treatment to be informed by genetic makeup, or drugs to be aimed at discrete subsets of the population. We recommend further investment in this area, which is complementary to general research into genetic risk factors in common disease.

Maintaining the UK's current competitive position in pharmaceuticals will not be dependent on expertise in drug creation alone. Developing "integrative biology" will also be important in relating gene sequence to function, physiology, and application. Immunology will be of particular importance, not just in discovering new therapeutic targets, but also as a means to improve drug delivery, specificity and targeting (eg in cancer treatment). There is potentially a large role for information systems in the health service in identifying and articulating social needs, and improving the base for trials and evaluation. The changing structure of the industry will mean that ever closer, more effective links between large businesses, SMEs, and the breadth of knowledge in the public science base become more critical. Facilitating communication, understanding and collaboration will be of real strategic importance. These areas have wider relevance beyond the pharmaceutical sector and are discussed in more detail elsewhere.

## Recombinant technology

Since 1973 recombinant research has underpinned the development of the biotechnology industry, allowing production of, for example, engineered enzymes for industrial biotransformation, recombinant vaccines, and humanised antibodies and their conjugates for therapy. To date, the recombinant technologies have focused on enzymes and other proteins as the direct product of gene expression, but attention is now beginning to embrace products synthesised by sets of enzymes. Metabolic pathway engineering is concerned with enhancing the performance of such enzymes to:

- enhance the throughput of pathways for greater productivity
- alter the specificity, or truncate pathways, to allow new products to be made
- transfer complex pathways to new organisms, typically to better hosts for large scale production.

Mastering these more advanced metabolic engineering techniques will be the key to the competitiveness of future biotechnology products (cf Delphi topic 77, Companion Paper B).

Metabolic engineering has obvious implications for product cost - to take a current example, transferring production of polyhydroxybutyrate (a biodegradable plastic precursor) from micro-organisms in fermenters, to plants, may give a tenfold reduction in cost. Increased productivity from a given nutrient input will also reduce waste and environmental impact. Transferring or modifying groups of enzymes will also be important in developing new types of product, particularly in generating improved strains of crop and farm animals, such as enhancing natural resistance to crop pests, or harsh environments, or improving the composition and proportions of oils in oil seed crops. In the longer term modification of complex enzyme systems may provide the basis for human gene therapy, perhaps in therapies employing engineered cells and tissues.

The UK's biotechnology industry is now second only to that of the USA in scale. Biotechnology will be of strategic importance for European high-technology industry and employment. The UK academic and industrial sectors are relatively strong in basic science and its application (see Section 3), and as mentioned above, the market for recombinant products is likely to continue expanding. **We recommend** that the UK should improve its competitive position in biotechnology, by maintaining scientific excellence in advanced recombinant techniques, and in particular metabolic engineering. We see particular opportunities in plant production of industrial materials, based on UK expertise in plant science, pressure for renewable materials, and under-utilisation of agricultural land. The report of the Agriculture, Natural Resources and Environment panel also highlights these issues and opportunities.

It will be important that this expertise is interwoven with whole-organism biology and bioprocess engineering, and has the closest possible relationship with innovative businesses. Within the science base, greater emphasis on integrating molecular genetics with biochemistry and cell biology in training and research will be important - particularly as regards the physiology of microbial recombinants, but integration with expertise in biochemical engineering, and an understanding of the industrial context of biological production is also important.

### Diagnostic applications of molecular biology

Opportunities for exploitation of new diagnostic markers will expand as current basic research, worldwide, unveils the detailed processes of biological systems and disease processes at genetic, molecular and cellular levels. Indeed, it could be argued that our new, specific knowledge of key biological molecules offers more opportunity for growth in diagnostics than in pharmaceuticals.

DNA-based diagnostics have obvious potential in prenatal screening, detection of predisposition to disease, or characterising pathogens or tumours - applications based on genome sequencing, and basic research into human genetics, and the genetics of disease. On a much broader scale, current research in developmental biology, cell biology, and immunology is identifying new receptors, cell surface markers, trophic factors, and adhesion molecules which will be of comparable value in identifying predisposition, finding and characterising disease early, and managing treatment.

While the UK diagnostics industry is relatively small, we believe the UK strengths in basic research that underpin the success of the pharmaceutical industry offer excellent growth prospects, in a large market area, and we **recommend** increased investment in strategic research in this area. There are relatively few barriers to development: many molecular diagnostics applications can be developed without a strong base in instrument engineering, and development times, and costs, are generally smaller than for pharmaceuticals.

### "Immuno-manipulation" and immunocompatibility

Immunology is a rapidly developing scientific field with pervasive and generic applications. Recent advances in understanding how immune responses are induced and controlled at the molecular and cellular level offer the prospect of developing a comprehensive model of the immune system and its control mechanisms over the next decade. This will provide opportunities for the design of new therapeutic agents which directly and specifically regulate the immune system, for instance, to control chronic immune and inflammatory diseases such as multiple sclerosis, rheumatoid arthritis or asthma, or to manipulate tolerance of transplants. It should also allow the development of improved vaccines against human and animal infection, and novel applications of vaccines in, for example, cancer treatment or fertility control.

Demand is strong. Vaccines against infectious diseases are the most cost-effective health intervention yet defined, and have been instrumental in reducing the incidence of the major infectious diseases. The global market is valued at about £2000 million, and demand for animal vaccines in particular may be expanded by the need to reduce antibiotic use in food animals. In immune and inflammatory diseases current treatments are palliative rather than curative. The true burden of chronic illness and disability in the population is difficult to quantify, but there can be no doubt of its social and economic importance, and greater emphasis on assessing the real burden of disease (rather than treatment cost) will inevitably strengthen the market for novel therapies. We recommend the UK should increase its investment in the basic and applied research relevant to achieving controlled interventions in the functioning of the immune system - for which the term "immuno-manipulation" might be coined.

The UK already has a reasonably sized, good quality presence in immunology, and is at the leading edge in key areas such as therapeutic antibodies and xenotransplantation. Basic research into the control of the immune system is also complementary to a range of other areas, including: techniques for transplantation; design and delivery of drugs and gene therapies; diagnostics; tissue engineering and biomaterials.

We would also highlight biologically derived materials and tissues, as a potentially important area for the future. Existing biomaterials are underpinned by organic polymer science: the technology is advancing quite rapidly, but the area is dominated by the USA, which has clear technical leadership. The academic base in the UK is relatively weak and the industrial presence is small. Future generations of implants are likely to be based on living tissues, organ parts, or materials produced by tissues: control of the growth, immunogenicity and behaviour of these cells, and their interactions with the host, will be critical. The UK has the potential to develop expertise in these areas, drawing on its strong expertise in immunology, developmental biology, and biotechnology, and its clinical expertise (eg in burns, surgery, and orthopaedics). We **recommend** that this area should be developed, and especially that clinical - basic science links should be strengthened. We see this recommendation as complementary to the Materials panel's emphasis on biomaterials (of all types) which enhance / encourage the restoration of function.

Information technology and infrastructure in medicine and health service research

The establishment of basic medical information systems in the UK and abroad, and continued improvements in the power and price of hardware, will open opportunities for more advanced medical information systems. The importance of information and communications technology in medicine is already widely recognised among those we consulted. Demand will be shaped by the long-term trends in health care, towards more systematic analysis of treatments and outcomes, improving the information base supporting clinical decisions, and protocol-based care. Some opportunities could be matched by current technology were the basic infrastructure in place, but most are also dependent on improvements in software technology, establishment of standards, changes in organisation and training, and better understanding of the psychological and sociological issues involved. Key opportunities for the UK are:

**Telemedicine** including remote monitoring and remote consultation, remote interventions, and virtual reality. Many applications in remote monitoring and consultation are already practical, and there is reasonable momentum towards further developments. The UK has reasonable expertise in the application of the technology.

**Integrating IT and medical imaging / diagnostics** including image processing, storage analysis and interpretation. Worldwide, there is growing demand and technical capability for non-invasive imaging / diagnosis using MRI, ultrasound, and other (non-ionising) modalities. The UK has academic strengths in the area, and while exploitation has sometimes been limited by the relative weakness of the instrument manufacturing sector, improved international alliances, and the growing importance of software for signal analysis and interpretation will lower this barrier.

**Systems for evidence-based health care** including the technology, skills, and infrastructure for compiling information on diagnosis, treatment, and outcomes on a national scale. There is a global need to respond to rising pressures on health services with greater effectiveness in clinical decisions, better use of technologies, and greater targeting of resources.

**Decision support systems** including systems to provide information, analysis, or options to assist in diagnostic, therapeutic and prescription decisions, and assist in organising treatment plans. Decision support systems will be an essential complement to medical information systems, assisting clinicians to make productive use of the available information on diagnosis, genetic prognosis, history, relevant trials and studies, prescription, and treatment options. Meeting this demand will require long-term research into computational methods, and organisational and behavioural issues: these areas are academically strong in the UK, though the commercial base is still weak.

We consider that the highest priority for the longer term is the development of the decision support (including image interpretation) systems, and we **recommend** increased investment in this area, which will be the most pervasive, with the greatest impact on the effectiveness of health care. For the medium term the most important step will be the development of the basic infrastructure for medical IT and evidence-based health care. This is far from simple, and has already received substantial investment: we **recommend** it should be given a high priority for the future. These areas not only build on the unique structure of the NHS, but in the longer term, offer opportunities for new forms of information-based service industries, and will contribute to product innovation throughout the health care sector.

In taking forward these recommendations, the findings of the IT & Electronics foresight panel should also be taken into account, particularly their emphasis on developing content-based information business, IT education, business environment, and telemedicine.

## Clinical research and research training

High quality clinical research conducted within the NHS is an essential element in wealth creation and social benefit, and its importance is likely to grow in coming years. Emphasis on evidence based medicine and rigorous evaluation in achieving effective, economical health services will increase the importance of large-scale trials and operational studies. The importance of a good clinical research base to the pharmaceutical industry is well established: good quality research will also be essential to derive full benefit from the emerging opportunities in decision support systems, molecular diagnostics, and genetic risk-assessment. The establishment of a basic medical IT infrastructure will increase the potential productivity of clinical research in epidemiology and outcomes analysis. The health services can also play an important role as a partner for industrial R&D - for example in collaborating to define needs, conduct pilot studies, and participating in mutually beneficial R&D.

There is no doubt the NHS has the potential to play an important and expanding role - particularly due to its scale, uniformity, and historic research strengths. At present it provides a base for clinical trials conducted to the highest international standards, and UK academic clinical research publications still have above-average citation rates. However, the UK position will clearly be threatened if the organisational and financial reforms introduced in recent years do not provide incentives to support R&D. In addition, ever increasing career and organisational pressures, which lead to more fragmented, small scale, and short-term studies, also tend to weaken academic clinical research.

Some of these issues have been highlighted in the Culyer report [24], whose recommendations we endorse. We see broader action as urgently needed to avert a decline in clinical research opportunities: we recommend the Department of Health should undertake major initiatives to strengthen research expertise among clinicians and allied professions across traditional boundaries, improve career and organisational flexibility for the best researchers, strengthen partnerships with industry, link capital spending plans with R&D needs, and ensure that the tendency to subdivide the NHS into separate competing trusts does not undermine the UK's ability to conduct increasingly important population based studies, large scale clinical trials, or innovative clinical research.

Whilst initially these developments might take place within the context of academic departments, in the longer term we would like to see more high quality research taking place throughout the NHS. In the longer term there will also be a need for a major review of all aspects of medical education and professional boundaries and interfaces.

## 4.3 BARRIERS TO PROGRESS

### Education and the science workforce

There is not, at present, a shortage of manpower at the graduate or doctoral level. Nevertheless, the UK must address several potential threats which could weaken the science base in the longer term. Much of our current graduate and postgraduate training has too narrow a base. The life sciences are developing and diversifying rapidly, and entering a phase where greater interdisciplinary collaboration and collaboration with the "users" of science are critical. In this environment versatility and breadth of understanding will be at a premium: we strongly support the moves towards broader, more comprehensive undergraduate and post-graduate training. While there is widespread agreement that an extra year's training is needed in most areas, requirements are diverse. Rather than recommend a single homogenous solution, we suggest a mixed approach, combining expansion of current MRes programmes with experimental four-year PhD programmes, and other approaches (eg four-year

undergraduate courses). Not enough of the best young people are being attracted into careers in science. One submission spoke of the need "... to rid the UK of its persistent preference for culturally educated but technically illiterate high fliers in so many domains of business and governance.". The issue must be addressed at several levels. At secondary school level, the National Curriculum has sought to ensure a general appreciation of science as a core subject. Whilst this is laudable, there is some evidence that it has reduced the numbers of the most able who chose A-level science subjects: a potentially serious consequence which must be addressed. However, changes in education will not be effective unless matched by improvements in the attractiveness of scientific careers in HEIs and the public sector, in terms of pay and career structure - and particularly the provision of a rewarding, reasonably stable career route for post-doctoral researchers who are not in the first echelon. The importance of industrial science careers, together with an appreciation of the importance of industrial innovation in national wealth creation must be emphasised at all levels of primary and secondary education. Finally it would be useful to develop elements of foresight in schools science education (which is usually historically based and too often unimaginative).

## Public understanding of science

Throughout our consultation work we encountered the view that in the UK the public, and especially those in positions of influence in business, education, government and the media, have either negative, or disinterested attitudes towards science and technology. We are not aware of any objective evidence that the public here have more negative attitudes than in other countries: indeed, the UK has been more receptive of biotechnology than most other European countries.

Nonetheless, we believe that a broad, general public understanding of current science and technology is an essential for any nation which expects to reap the full economic and social benefits of science. We support the good work already in train in this area by COPUS, the Office of Science and Technology, the Royal Society, The Wellcome Trust, the Research Councils and others: this work should be continued and expanded, and should include dissemination of the Foresight vision of the applications of science and technology.

Over the longer term, the general level of scientific understanding and interest is likely to influence the status of science as a career, the willingness to invest in research and new technologies, the ability of specialist and non-specialists to form productive partnerships within industry, and thus the ability of a country to maintain and exploit scientific expertise.

Equally important, society must be able to engage in broad debate about the ways in which technology is used. We do not, of course, expect that a better informed public will inevitably align with the views of the scientific community. This is neither plausible nor desirable. However, the greatest danger is that lack of information produces indiscriminating risk-aversion, or blind complacency. The public must be able to participate in carefully judged choices, with sufficient mutual understanding between specialist and non-specialist for debate to be positive and constructive.



## 5. RECOMMENDATIONS FOR IMPLEMENTATION

### 5.1 COMMENTS ON IMPLEMENTATION

#### Practical implementation

Co-ordination between research funding bodies (including industry) is central to implementation, as many issues cross traditional boundaries. For each recommended action below we have listed the organisations / groups that should be involved in implementation. In each case we have also indicated a single organisation - the first named organisation - charged with taking the lead in implementation.

In considering the action that might be taken to address or develop the priority issues and areas, we have been as specific as possible. Nevertheless, most recommendations remain quite broadly framed. Successful implementation will require cohesive, focused, programmes, and much will depend on the expertise with which programmes are directed, and on the further narrowing, refinement and definition of the forward vision.

Implementation will also depend on effective management of large strategic research programmes. There is some concern that current methods could be improved, but the panel has not had time to address these in detail. It will be important to establish:

- new ways of achieving concerted action across Research Councils, IIEFCs, universities, DoH, industry, charities and other groups. This is especially important in the case of universities, where existing funding mechanisms tend to promote competition rather than collaboration.
- procedures for reviewing and re-defining the strategic vision and aims of foresight initiatives.
- procedures for assessing the long term social and economic value of foresight initiatives.

Co-ordination does not necessarily involve jointly funded and managed programmes: in some cases projects may be strategically co-ordinated but managed by one organisation, in others funding and organisation will be joint. It is up to the organisations involved to determine the best way forward for implementing their portfolio of recommendations.

#### Role of academic research

Academic research groups are most effective in the realms of medium and long term basic and strategic research. Though in some areas it might be beneficial for more effort to be devoted to developing knowledge to the point where it can be exploited by the users (eg industrial / health service R&D), we would not wish to see major changes in the core role of the universities. We see greater involvement of universities in strategic Foresight science and technology programmes as a means of improving the focus, direction, and linkage of their work rather than diverting them into new types of work.

## Balance between strategic initiatives and other forms of funding

The panel was asked to set its recommendations in the context of the overall balance between strategy-led and response-mode funding in public spend. These concepts are subject to many different interpretations, and since information on the current balance is unreliable, any model must be subject to further debate and analysis. Given the scale and nature of the initiatives we recommend, we would propose a model in which:

- one quarter would be allocated to narrowly focused initiatives based on Foresight
- one quarter would be allocated to strategic research programmes, relevant to broader Foresight priority areas (eg ageing) or areas previously identified as strategically important (eg genome mapping).
- half would be allocated to response mode funding for "blue skies" research across all areas. The work supported would be science-led ("ideas-led") and funding decisions would be based primarily on scientific merit.

This would have to be a long-term goal. Funding for new initiatives is most effective if built up gradually over a number of years: we would certainly not expect Foresight initiatives to approach this scale before the end of the century, and not until at least one more Foresight exercise has been completed.

## European Community R&D

The strategic priorities identified by the panel emerged from consideration of UK opportunities, strengths and weaknesses. Nevertheless, in taking forward actions and initiatives, it will be important that the Office of Science and Technology considers the potential for co-ordination with EC programmes. The Fourth Framework programme includes major programmes on Biomedicine and Health, and Biotechnology, which encompass priority areas such as chronic diseases of age, application of genome information to human health, and basic plant sciences for biotechnology. The programmes on Telematics and Information Technology also encompass many areas relevant to medical information systems.

## 5.2 ACTIONS AND INITIATIVES RECOMMENDED

Infrastructure for the development and exploitation of the life sciences

New company formation and funding

Tax regulations should be reviewed, with a view to promoting investment in SMEs by establishing a transferable tax credit based on funds sunk into research and development in small high-technology companies which do not record pre-tax profit. Action: Treasury/DTI

Stock Exchange rules should be loosened to allow early investors (individuals or venture capital firms) flexibility in realising their investment after flotation. Action: Stock Exchange / Treasury / DTI

The DTI should actively promote the development of a European equivalent of NASDAQ

The interface between academic research and industry

HEFCs, together with Research Councils and charities (in postgraduate training) should promote the

inclusion of some relevant experience and education in exploitation and business issues as part of undergraduate science training, and broader PhD programmes.

HEFCs, together with Research Councils and DTI, should promote greater investment in university technology transfer groups, and particularly the development of specialist teams serving several universities (perhaps on a regional basis), to allow access to a greater range and quality of expertise than would otherwise be economic.

The HEFCs, together with DTI, should promote an experimental programme of "industrial fellowships" in universities. These should be funded mainly by industry, offset in part by tax incentives or cost-sharing. The aim should be to increase the numbers of individuals with expertise gained in industrial R&D undertaking relevant strategic research within university centres of excellence.

In proposing this series of initiatives on cultural and organisation barriers, we recognise that the quality of execution will be of the utmost importance, and especially challenging. The calibre of individuals and positions involved in transfers, the suitability of business experience and education schemes will need careful consideration, and adequate resources must be set aside for evaluation of these initiatives.

#### Co-operative programmes within the university sector

The HEFCs should review the criteria used in research assessment exercises to provide modest incentives to centres of excellence collaborating on major projects. The scheme should not need to draw in additional funds, merely re-focus existing support. An example would be to develop stringent entry criteria to identify truly complementary, high quality, collaborations, and allow "double counting" of activities meeting these criteria.

#### Technology incubators

DTI and local government, drawing on EC regional funds where relevant, should form a limited number of additional technology incubators attached to suitable centres of life sciences research.

#### The physical infrastructure for life sciences research in universities

The HEFCs should instigate a major programme of capital investment in refurbishment and equipment in high-quality university life sciences departments.

Office of Science and Technology, should convene a forum involving the medical charities, the HEFCs, research universities, Departments of Health and Education, DTI and industry to address the problems of full and marginal costing and infrastructure costs in universities. One possible solution might be for HEFCs to further subsidise (eg to the level given to Research Council projects) high quality, peer reviewed, charity research which contributes to the general science base (in return for which the universities would retain IPR and the onus to exploit); but for charities to pay the full costs for research which addresses narrow interests, and for which the charities retain (if they wish) intellectual property rights.

#### Integrative biology

Research Councils, together with relevant charities, should initiate scientifically and conceptually broader PhD and post-doctoral fellowship programmes which draw together molecular genetics, cell biology and physiology.

Research Councils, together with medical charities, MAFF, DoH and industry should initiate appropriate cross-disciplinary "flagship" programmes of integrative biology. Possible areas might include ageing, neuroscience, nutrition, immunology, or plant biology.

Research Councils, together with charities and industry should strengthen research programmes in cell biology, and in particular cell-cell and cell-environment (extra-cellular matrix, growth factor, hormone, biomaterial) interactions.

There is a good case for modest additional investment in cell biology and training in the next five years. On the whole we would see integration being improved gradually, primarily through the re-structuring of existing projects, programmes, and training. In some cases it will be appropriate to create new positions in order to further integration, in others the key will be networking.

### Neurosciences and cognitive sciences

A major initiative, led by MRC and involving BBSRC, EPSRC, DoH, industry and charities, should be formed to strengthen strategic research into the molecular, cellular and behavioural basis of the development and decline of human cognitive function due to non-specific deterioration as well as the major neurological diseases.

MRC, together with ESRC, BBSRC, relevant charities, and DoH should form a joint programme of basic research into the relationships between brain function, mental state, immunology and good health.

Given the nature of the field, and the current average position of UK science, we believe that the UK should aim for a major, long-term increase in investment in neurobiology and cognitive development and decline.

### Age

A major joint initiative, led by MRC with BBSRC, MAFF (and relevant industries and charities) should be launched to understand the basic processes causing ageing in man, animals and plants, combining genetics, cell and developmental biology, systems, and population studies, and including comparative studies.

Industry, together with MRC, BBSRC, medical charities, and DoH should form a strategic research initiative into the fundamental mechanisms underlying the major age-related degenerative diseases (eg osteoarthritis, osteoporosis) to stimulate development of therapies, diagnostics and treatment strategies.

DoH, together with industry, ESRC, and EPSRC should collaborate in strategic and applied research programmes - encompassing medical, ergonomic, sociological, bio-engineering, systems, and materials aspects - to stimulate development of relevant, life-style supporting equipment and systems for the elderly and infirm.

ESRC should instigate a research initiative into ways of better harnessing the talents and experience of the ageing workforce in current and future organisations and working environments.

MRC, together with BBSRC, HEFCs, relevant charities, and DoH should facilitate the development of centres of excellence in ageing research within the UK to provide a focus for interdisciplinary activities and provide training for future researchers.

The major capital cost of a National Ageing Research Centre, linked to an appropriate university, should be sought from the millennium project. The bid should be co-ordinated by a relevant medical charity (e.g. Research Into Ageing), drawing in expertise and funding from DoH, MRC, BBSRC, HEIs, DTI, industry and other charities. In addition to a strong in-house research programme, the centre should help to co-ordinate activities in other centres of excellence nationwide. As well as the areas listed above, the remit of the centre might include neurodegeneration research ( 5.2.3 above).

### Genetics in risk evaluation and management

DoH, with MRC, should develop major long-term research programmes evaluating the interactions between genes, environment, development and early life experiences and lifestyle in major disease, and the effectiveness of "probabilistic medicine" and lifestyle interventions based on this knowledge. The programmes will need to involve research at both the biological and epidemiological levels, and build on existing expertise in molecular epidemiology, diagnosis, and health promotion. Determining the effectiveness of individual risk-assessment on lifestyle modification and health is likely to be a 20-30 year experiment. MRC, together with BBSRC, medical charities, MAFF, HSE, and DoH should initiate research programmes addressing specific aspects of gene/ environment interactions, including:

- genetic variation and nutrition
- genetic variation and environmental toxicology
- interactions between developmental programming and genetic variation

### Drug creation and delivery

HEFCs, in collaboration with selected universities and businesses, should promote undergraduate and post-graduate courses which combine training in chemistry and modern molecular and structural biology, ideally with experience in industrial applications.

Using joint industry, BBSRC, MRC, EPSRC, DTI (eg LINK, ROPA) programmes of strategic and basic research, UK capabilities in the following areas should be strengthened:

- molecular diversity and molecular recognition (including modelling tools for structure-based drug design)
- technologies needed for gene delivery and drug delivery (eg membrane transport)

Industry, together with MRC and BBSRC should initiate research programmes in pharmacogenetics (eg the genetics of drug dyscrasias).

The UK already has a reasonable position in this area: much could be achieved through a relatively modest, sustained, increase in investment, combined with a re-focusing of existing resources.

## Recombinant technology

BBSRC, together with MAFF, industry, and DTI (through LINK and other programmes) should strengthen investment in research into fundamental metabolic pathways and their regulation, and application in metabolic engineering as a foundation for future industrial and health-related developments.

BBSRC, together with MAFF and industry should strengthen integrative biological work (especially plant genetics, biochemistry, and physiology) relevant to biological manufacture of industrial products.

Given the UK's relative strengths in the area, we believe a good competitive position could be achieved with modest, but sustained, additional investment and improved co-ordination of existing spend. However in this area it will be particularly important that schemes build better links between public and private sector research, improve vertical integration (eg combining technology / process/product innovation), and nurture interdisciplinary working and skills.

## Diagnostic applications of molecular biology

DoH, together with DTI, MRC, BBSRC, and industry should initiate strategic research programmes - with significant additional investment - to develop links between basic research in cell and molecular biology, clinical pathology, and industrial R&D to promote development of new medical diagnostics.

MRC, together with DoH and the HEFCs should promote basic research and training in molecular pathology.

## Manipulating the immune system, immunocompatibility

A joint research initiative involving industry (in the lead role), MRC, BBSRC, and DoH should be formed, on the manipulation of the immune system by control of tolerance, in vaccination, and in chronic inflammation.

BBSRC, together with MRC, DoH, and EPSRC, and with industrial collaboration, should form a research initiative in strategic and clinically applied research into non-immunogenic implants of biologically derived materials, tissues and organs.

## Information technology in health sciences

DoH and industry should initiate collaborative research programmes in the basic science and technology relevant to advanced intelligent clinical information systems, including decision support systems, image interpretation, and protocol based care.

Industry and DoH should give a high priority to long-term collaborative projects developing the methods, technology and skills needed for a national health information infrastructure to support the practice of medicine (evidence based clinical practice), and large-scale medical and epidemiological / outcomes research.

In both these programmes, training of medical and professional staff, both as users of future systems and as researchers in informatics, should be given a high priority.

## Clinical research and research training

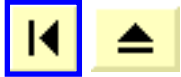
The Department of Health and MRC, with the medical research charities, Royal Colleges and other professional bodies, should give a high priority to developing and implementing strategies for: innovation in, and organisation of, clinical research; developing researchers with expertise spanning traditional professional boundaries (eg clinician/ industrialist, clinician/ scientists, clinician/economists, clinician/ IT specialist); facilitating collaborations with industrial R&O; and fostering high quality R&D throughout the NHS.

The Department of Health should strengthen career opportunities (at all levels) to permit key individuals to devote substantial amounts of time to research. Mechanisms should be developed to link the NHS capital budget more effectively to the needs of quality R&D.

The BBSRC, together with MRC and medical charities should develop training and fellowship schemes to achieve a (modest) increase in the number of clinical veterinarians, trained in, and conducting high quality research. Particularly important are the areas of comparative medicine and veterinary pathology as these underpin the development of animal models for human disease.

  [Contents](#)





## 6. CONCLUDING REMARKS

### Review of progress

The first national Technology Foresight programme has been a challenging and fascinating exercise for all involved. Much new ground has been broken, and it is vital that, alongside implementation, there is a thorough independent review of the process and its effectiveness. There are clearly lessons that could be learned for the future - for instance in the way the Delphi process is used, or in the provision of descriptive and benchmarking information earlier in the process.

The Technology Foresight programme has, in our view, achieved many of its objectives, particularly in involving a broad cross-section of individuals and organisations in developing a strategic vision for UK science and technology. The exercise should certainly be repeated - probably every five years, though since this first programme was to some extent a learning exercise, a shorter period might be justified at first.

There are strong arguments for maintaining the panel, in a less active form, and with a substantial change in membership, between exercises. This would allow some involvement in implementation, to ensure effective dissemination, and to provide the panel with direct feedback to inform the planning of future exercises. To derive full benefits from the exercise, implementation will have to be brisk and decisive: we recommend that, as a check-point and as a learning exercise, the panel should meet with all those involved in implementations (Research Councils, Government Departments, trade associations) to review progress 12 months after publication.

### Areas for future study

Two areas surfaced late in the benchmarking and consultation exercise and due to time constraints we have not examined them in as much detail as would like. We recommend them as a starting point for the next foresight exercise.

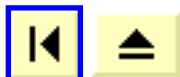
**Tropical medicine.** Although overall the field is very small, the UK has a strong presence in tropical medicine research. Patterns of population growth will undoubtedly increase need, and as some tropical countries develop economically (eg Pacific rim countries) commercial opportunities will expand, while affluence, sanitation and education will change needs. We have not explored implications for industrial and academic research strategies, or exploitation of research for humanitarian or commercial ends.

**Social sciences in medicine.** Advances in medical technology and innovations in health care resource allocation, organisation, and evaluation, must be linked with effective sociological R&D if the UK is to benefit fully. In this report we have highlighted some of the more obvious needs in areas such as ageing, genetic risk indicators, and medical application of IT, but we have not been able to address the suitability of social science co-ordination, direction or linkage for these and other future needs.



[Contents](#)





## 7. REFERENCES

### Companion papers

- A Benchmarking information on research investment and research outputs
- B Delphi survey: survey methods and findings
- C Consultation exercise: overview of responses

### Further reading on Foresight

- The context of foresight. U Sparrow. (OST 1994)
- Innovation and foresight. R Freeman. (OST 1994)
- Turning research into wealth: the Japanese way. J Chisholm (OST 1994)
- Foresight Forum Proceedings (OST 1994)

### References and footnotes

- [1] Growth, Competitiveness, and Employment: The challenges and waysforward into the 21 st century. Commission of the European Communities 1993
- [2] Technology Policy and Critical Technologies. A summary of recentreports. M. Moguee. (National Academy Press 1991)
- [3] Healthcare systems: Cost containment versus quality. E Feldbaum, M. Hughesman. (FT Management Reports 1993)
- [4] Global pharmaceuticals. S Rickwood. (FT Management reports 1993)
- [5] Reform, restructure, renewal: The Ernst and Young ninth annualreport. (1994)
- [6] European Biotech 94: a New Industry Emerges. (Ernst and Young 1994)
- [7] Public-private linkage in advanced technologies. W Faulkner. (End ofaward report, ESRC, 1992)
- [8] Studies by the Centre for Business Strategy, London Business School
- [9] Forward Look of Government Funded Science, Engineering andTechnology. Cabinet Office (HMSO 1994)

- [10] Assessment of critical technologies in Europe in selected fields covered by the EC research programmes. F Narin, M Albert. (1994)
- [11] "Critical condition: clinical research in UK fading fast" (Science Watch 1992)
- [12] PHARMA facts and figures. (ABPI 1993)
- [13] UK Biotech '94 - the way ahead. V Spencer, K Binding (Arthur Anderson 1994)
- [14] Diagnostics beyond 2000. The Diagnostics Club. (1993)
- [15] Community policy for biotechnology: economic benefits and European competitiveness. SAGB/ CEFIC (1994)
- [16] Compendium of health statistics, 8th Edition. R Chew (Office of Health Economics 1992)
- [17] The Challenges of Ageing (ABPI 1991)
- [18] Innovation and the Tax System. ACOST. (HMSO 1994)
- [19] Massachusetts Biotechnology Research Institute. (1994)
- [20] An assessment of firms located on and off Science Parks in the United Kingdom. P Westlead, D Storey. (HMSO 1994)
- [21] Wealth generation in the Healthcare and Pharmaceuticals sectors. (Sciteb 1994)
- [22] Supporting the science base (ABPI 1992)
- [23] The essential role of Integrative Biomedical sciences in Protecting and contributing to the health and well-being of our nation. P Jobe et al. (Biomedical Sciences Vol. 37(3),1994)
- [24] Supporting Research and Development in the NHS. A Culyer. (HMSO 1994)
- [25] Science Watch July/August 1993 and May 1992. In the former, LMB, Cambridge, NIMR in London, and the ICRF Laboratories in London were ranked in the top 25 in the world for the impact of their work between 1988 and 1992. In the latter, eight UK centres were ranked in the top fifty, for work between 1981 and 1991.
- [26] International patent indicators of US position in critical technologies. M Moguee, R Kolar. (Report to the Science and Engineering Indicators Program, NSF, 1993)

## Acknowledgements

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## Abbreviations

ACOST	Advisory Committee on Science and Technology
BBSRC	Biotechnology and Biological Sciences Research Council
CEC	Commission of the European Community
COPUS	Committee on Public Understanding of Science
DoH	Department of Health
DTI	Department of Trade and Industry
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
HEI	Higher education institute
HEFC	Higher Education Funding Council
HSE	Health & Safety Executive
LINK	A programme of collaborative research projects involving academia and industry, funded equally by government and industry. LINK is co-ordinated by OST.
MAFF	Ministry of Agriculture, Fisheries and Food
MRes	Master of Research degree
MRC	Medical Research Council
NASDAQ	National Association of Securities Dealers Automated Quotations (USA)
OECD	Organisation for Economic Cooperation and Development
ROPA	"Realising Our Potential Award". A grants scheme administered through the Research Councils, targeted at academic researchers already collaborating with industry, with the aim of consolidating these links.
SME	

Small to Medium sized Enterprise. Defined as a business employing less than 250.



[Contents](#)



# Progress Through Partnership: 4 Health and Life Sciences

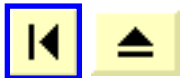


[Contents](#)



## 8. ANNEXES

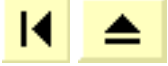
- Annex 1 [Terms of reference](#)
- Annex 2 [Programme of work](#)
- Annex 3 [Workshops](#)  
Aims, participation, workshop reports
- Annex 4 [Discussion papers](#)  
- Financial factors influencing investment in new technology (Dr H Hale)  
- Medical IT (Professor C Taylor)
- Annex 5 [Panel's initial "Hypotheses"](#)



[Contents](#)



# Progress Through Partnership: 4 Health and Life Sciences



[Contents](#)



## ANNEX 1

### TERMS OF REFERENCE

#### 1. Definition of the Sector

The panel's initial terms of reference defined its range of concerns as follows:

##### Overall Scope

The panel will cover the markets and technology for health and life sciences, including pharmaceuticals. It will exploit relevant existing material relating to health care and life sciences including the ACOST report on Medical Research and Health.

##### Related sectors

The work of the Materials, Agriculture/Natural Resources/Environment, Chemicals, Food/Drink and Leisure/Education sectors is considered particularly relevant to the work of the Health and Life Sciences panel.

##### Market

The panel will need to consider the changing market pull in health care and the challenge it presents to industry and the health services. This will reflect a number of different factors including: demographic changes, particularly increasing elderly population with the concomitant increase in the burden of degenerative diseases; shift from hospital to primary and community care and increased use of day care surgery; health service based on greater knowledge of needs and the requirement to keep the overall costs of health provision within an acceptable proportion of GDP; the altered patterns of health following changes in the physical environment, and as a result of global threats especially population expansion, new infectious diseases and pollution; shifting social environment, and the health consequences of social change eg drug addiction; impact of health related behaviour and of social acceptability of new health care provision, eg of artificial organs or xeno-transplantation; regulatory and purchasing strategies for therapeutics.

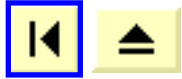
##### Technology

There is a common research base providing the technological push in both health and life sciences for example vaccines for human and animal diseases, diagnostics including measures of environmental toxins, genome studies contributing inter alia to insecticide resistant crops, improved animal strains as well as identifying new pharmaceutical targets, studies of molecular structure for drug design or insecticide development.

## 2. Aims

The initial terms of reference specified that the final report of the panel should cover:

- (a) the factors it considers important in future markets, including some assessment of their relative importance;
- (b) an assessment of promising opportunities for matching new scientific, engineering and technological advances to future markets; and
- (c) the panel's perceptions of the strengths and weaknesses of the UK industrial, scientific engineering and technologies base as identified during (consultation) and as identified in the benchmarking work of the OST's Foresight team.



## ANNEX 2

### WORKING METHODS

#### 1. Introduction

The Office of Science and Technology's overall plan for the Technology Foresight Programme prescribed many elements of the Health and Life Sciences panel's work. These included the initial opinion survey, the Delphi survey, workshops, and the timetable for the work. Within this framework, the panel was free to choose the methods and sources used, and drew on accounts of foresight methods used elsewhere, on the advice of the consultants assisting with the programme, and their own evolving experience of the task. In line with the broad, fast-moving nature of the programme, we deliberately avoided the formal and highly structured approaches used in other studies, (eg those of BMFT in Germany). For instance, we did not attempt to create a comprehensive taxonomy of areas of science, applications, and their relationships. Ideas and issues were usually elaborated and recorded in internal discussion papers or consultation papers. The flow chart overleaf summarises the final sequence of work.

#### 2. Developing initial ideas

The panel's first and second meetings were mainly concerned with developing ideas on the trends, driving forces, and scientific opportunities that will shape change in technologies, products, and services. Before the panel first met, members' ideas were collected by post, and compiled into a "menu" of over 130 topics and issues, and there was a further brainstorming session at the first meeting. After some additional, informal, consultation with experts outwith the panel, these were elaborated in short internal discussion papers addressing overlapping market, health, and scientific viewpoints.

To provide an independent "second opinion", a questionnaire was sent to fifty experts chosen from the co-nomination pool, and/or nominated by members. The questionnaire was designed by PREST, and asked for views on: trends and issues influencing the sector; possible new market opportunities (arising from the trends); possible new products, processes or services (related to new markets); scientific and technological advances underpinning new products or services. Twenty-seven responses were received and tabulated. There was considerable consistency among these responses at the broad level of trends and markets, and between the responses and the ideas developed by the panel. The trends frequently highlighted were:

- the increasing numbers of elderly people (10 respondents)
- the increasing costs of health care (10)
- increased environmental pollution (6)
- harnessing IT in health and the life sciences (5)
- understanding the genetic basis of disease (5)
- growing importance of health promotion (4).

As might be expected, views on products and the key issues in the underpinning science were more diverse.

### 3. Links with other panels

Individual panel members were given responsibility for maintaining links with the five panels most closely related to the Health and Life Sciences sector: Agriculture, Natural Resources and Environment, Food and Drink, IT and Electronics, Chemicals and Materials. Links were maintained through exchange of minutes and discussion papers, and/or informal meetings.

### 4. Scenarios

The panel did not develop formal scenarios, due to time constraints, though we drew, to a limited extent, on previous work by other groups. A series of "Hypotheses" were developed at the second and third meetings. These explored the possible implications of separate, narrow, groups of related trends and the degree of uncertainty involved. Unlike scenarios, they did not attempt to produce comprehensive, integrated visions of the future, and were kept short, and, in some cases, deliberately provocative. We found this a practical approach, particularly as it quickly provided concise and accessible material for the consultation exercise.

### 5. Consultation

The three main elements of the panel's consultation work:

- Delphi survey,
- foresight workshops,
- invited submissions based on the "Hypotheses",

are described separately in companion papers B and C, and Annex 3. The panel also met with some of the key organisations involved in the sector. Panel members met with representatives of the Association of British Pharmaceutical Industry, Biotechnology and Biological Sciences Research Council, Department of Health, and Medical Research Council, to discuss initial views and the "Hypotheses" in August 1994, and again in January 1995 to discuss the second draft report.

The panel also organised meetings with the Association of Medical Research Charities to discuss the charities' role in the sector, and with representatives of venture capital groups and Treasury, to explore the fiscal and organisational environment for high-technology business start ups. Numerous other organisations and individuals contributed their views, formally or informally, in meetings with panel members or secretariat, and the Human Nutrition Research Forum and Oxford Trust held parallel foresight workshops at which the panel was represented.

*1 The panel was given access to the "Hemingford Scenarios" developed by Anglia and Oxford RHA, to "mini scenarios" prepared for the Wellcome Trust/MRC/BHF foresight exercise in cardiovascular medicine, and generic scenarios developed for the programme by Oliver Sparrow. Published works such as "Britain in 2010" (J Northcott, Policy Studies Institute), were also used.*

### 6. Benchmarking

To assess the current strengths and weaknesses of UK industry and industrybased R&D the panel used previous studies and economic indicators, and the views presented in consultation. To assess strengths and weaknesses in academic science the panel commissioned a bibliometric survey of research outputs for the UK and eleven other countries. These provide comparative indicators for the output and perceived quality of total national activity in each of eighteen broadly drawn disciplines. To complement these indicators, the panel also drew on subjective views of the performance of the UK's world-class centres of excellence relative to those in other countries, and the UK's performance in the most important and rapidly moving sub-fields within broad disciplines. The results of the bibliometric exercise are available as companion paper A. The principal findings, from all sources, are given in Section 3 of the report.

## 7. Reaching conclusions and identifying priorities

The panel began the process of identifying possible priority areas only after the bulk of the consultation work was complete. The prioritisation criteria used were those suggested by the Technology Foresight Steering Group:

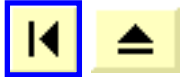
- Economic and social needs and benefits
- Scientific and technological opportunities
- Potential to apply (in UK)
- Scientific and technological strengths
- Cost (cost/difficulty of reducing any gap between current position and that desirable)
- Timing (the extent to which the opportunity falls into the foresight timeframe)

The criteria were applied through an iterative process, beginning at the panel's fifth meeting with a short list of potentially important areas and issues, and continuing through to the eighth meeting. As new information and opinions from the consultation and benchmarking exercises became available throughout this period, we took care to ensure there was scope for major change at each stage in the iterative processes, so that initial assumptions and assessments did not carry undue weight.



[Contents](#)





## ANNEX 3

### WORKSHOPS

#### 1. Introduction

The Health and Life Sciences panel organised five workshops during October and November 1994. The prime purpose of the workshops was to allow a sample of the academic, industrial and medical communities to advise the panel on the issues, opportunities, and initiatives they felt were most important. Workshops were also intended to help build regional networks, to allow the panel to explain Foresight to the broader community, and discuss their concerns, and to provide the panel with direct feedback on the Delphi questionnaires.

The workshops held were:

- October 3 "Biotechnology", Cambridge University (Run as a joint workshop with the Chemicals panel)
- October 7 "Diagnostics and therapeutics", University of Manchester.
- October 19 "Major disease areas - emerging opportunities", Edinburgh University. October 28 General workshop, Dunadry, Co. Antrim. (Run jointly with the Northern Ireland Office's Industrial Research & Technology Unit)
- November 3 "Health delivery / health promotion", Southampton University

#### 2. Organisation

The typical programme for the day involved initial presentations on foresight, followed by an overview of the results of Delphi questionnaires<sup>{2}</sup> completed by workshop participants beforehand. Most of the day was spent in open discussion in two or three syndicates. Syndicates were asked to consider whether the panel had correctly identified the major trends in the area, and to debate which opportunities or issues might be of major economic and social importance in the longer term. The day concluded with discussion of the syndicates' conclusions, and discussion of the broader policy issues related to foresight.

*{2} Workshop participants were asked to complete a Delphi questionnaire - identical to that used in the main postal Delphi survey - and return it to the consultants, Scientific Generics, before the event.*

*{3} Syndicates were generally free to choose the areas for discussion which they felt were important, from material provided by the panel. At the Cambridge workshop each syndicate was given a set of specific (sometimes provocative) theses to debate.*

The workshops were chaired by Dr David Gani (Chemicals panel), Dr Barry Ross, Dr John Gordon, Professor Mark Ferguson, and Professor Steven Holgate. Syndicate groups were chaired by invited

participants, though each included at least one panel member, who advised on relevance, level of detail etc.

There were a total of 123 participants, of whom 27 were from industry, 76 from academia, health services and medical schools, and 20 from government bodies, professional associations, and other groups.

### 3. Output

As well as panel members attending workshops and participating in discussions, the panel was provided with detailed notes of each workshop, and the results of the Delphi forms completed by participants, for the following panel meetings. This annex is condensed from these reports.

The report on the workshops by Scientific Generics (who provided consultancy support) contains a short note of the most pervasive themes discussed, and detailed accounts of typical workshop organisation and methods. The discussions of the Delphi survey, and the comments made on Delphi forms, were used to inform the panel's interpretation of the main Delphi survey, and are discussed further in companion paper B. Delphi responses from workshop participants were not merged with the main data set from the postal survey.

### 4. Workshop opinion: the Foresight process

In discussion of Foresight itself three points were consistently made:

- Results from the Delphi questionnaire should be interpreted with caution. The coverage of questions is inconsistent and the quality of the wording is sometimes poor. The complexity of the form, and the breadth of expertise needed may mean that many responses are not valid.
- While a forward-looking science strategy is needed, the UK must retain a substantial base of publicly funded, "blue skies", ideas-led research. Areas of combined scientific and social/economic importance should not be funded from the science base alone, but should also draw in industrial funding.
- The most valuable output of Foresight might be the development and maintenance of publicly funded, well managed workshops to draw together issues in academic research, training, industrial R&D, bridging gaps between disciplines and sectors.

### 5. Workshop opinion: trends and driving forces

In general, participants supported the panel's views of the principal trends driving change in the sector.

#### Social and Environmental

- Demographic changes, leading to an ageing population and a greater burden of chronic diseases
- "Green" pressure for cleaner, low-input production, safer products, and
- less use of pesticides, antibiotics etc in agriculture
- Changing health policies across the developed world
- "Health consumerism"

## Commercial

- Pharmaceutical R&D portfolios becoming more tightly focused
- Growing importance of small businesses in innovation, in the pharmaceutical, biotechnology and instrumentation sectors

## Technological

- Greater strategic emphasis on the life sciences in Germany, Japan and other countries increasing the competitiveness of this sector
- Broad ranging impact of IT on the life sciences
- Opportunities arising from advances in molecular genetics

There are important cross-linkages between trends. For instance an ageing but wealthy population will tend to promote the development of health consumerism as they seek ways to have their needs addressed irrespective of national priorities.

The trends in human health needs and health structures were discussed in further detail at the Southampton workshop. The additional variables which will change over the longer term include:

- Lifestyle, workplace, and family structures. Wealth and social inequality
- Changing environmental hazards, climate change, new diseases
- Attitudes to individual responsibility
- Public expectation of health improvements

Long-term changes in health structures might include:

- Continued moves from acute to primary care, and increased emphasis on care and rehabilitation rather than cure ?
- Greater emphasis on public education, involvement and individual responsibility - possibly linked to positive or negative incentives to encourage individual responsibility ?
- Greater emphasis on health economics and effectiveness measures, linked to an increasing trend towards restricting care options, and requiring closer integration of economic assessment with development projects ?
- Possibility of more inequality in the levels of resources allocated to individuals (eg through parallel payments by the affluent, or discrimination against those with "preventable" conditions).

## 6. Workshop opinion: science, technology, needs and markets

### Advances in molecular genetics and genome sequencing

The UK has developed a strong scientific position in gene identification and analysis. As the genome project progresses, and as more sequences become available, new scientific and technological abilities will be needed to exploit this information in disease prevention, diagnosis, new treatments, or in individualised care. Workshop participants stressed the key scientific challenge of integrating sequence information with cell function, physiology and pathology, and the need for better techniques and skills for linking sequence to function. Commercial and medical exploitation may include opportunities for new nucleic-acid diagnostics, gene delivery / expression technologies, new

applications of pharmacogenetics (eg in tailoring treatment to reflect individual genetic variation), or genetic risk measures. Participants agreed that gene therapy was a promising and very important technology, but the panel was cautioned against over-estimating the scale of impact on medicine, or its rate of development.

Clarifying the genetic risk factors involved in common multi-factorial diseases such as cardio-vascular disease or cancer will be another important area for the next 10-20 years. It might become possible to use individuals' genetic makeup, lifestyle and environment to individualise risk and target interventions, but it is questionable how widespread and useful this would be at a population level. The effectiveness of public health interventions is strongly influenced by education, culture, affluence and other variables. Identifying risk without changes on other areas might have little impact.

## Genetic manipulation

Genetic manipulation of plants, animals and micro-organisms was discussed in depth at the Cambridge biotechnology workshop. Participants highlighted a very diverse range of products and opportunities, including animal production of pharmaceutical proteins, engineered catalytic enzymes, plant production of intermediate-bulk feedstocks for the chemicals or textile industries, engineered foods with novel properties, and genetic manipulation in xenotransplantation. Plant production of chemical feedstocks was the subject of particularly detailed discussion: it was proposed that intermediate bulk chemicals offered the greatest potential for growth, as markets for high value speciality products (eg antibodies) would be limited, and very large scale production (eg of biodiesel) might not be competitive in the UK climate.

A unifying theme was concern that external factors would prevent technological and market opportunities being realised. Key among these were: the difficult funding environment for start-up companies in the biotechnology sector; poor public understanding of science, leading to suspicion and hostility; the need for broader, more multidisciplinary training in science; poor networking between academic and industrial sectors, and between primary producers and downstream processors; and poor standards of education and training.

## Age and Chronic disease

Ageing populations will mean a long-term increase in chronic disease, disability and dependence. There was a strong feeling among participants that age is one of the key health issues, but needs to be tackled at two levels. Firstly, there is a need for a better understanding of the cellular, molecular, and physiological processes involved in ageing and chronic diseases, to lay the foundations for treatments that might eventually slow deterioration, or alleviate its effects. Secondly, there is an immediate need for treatments, devices and systems to allow the infirm and dependent to maintain a reasonable level of independence, and contain the social and financial burdens. Some advances would be dependent on major scientific advances (eg cognitive prostheses), but much could be achieved now with current technology. The "market pull" is still quite weak, though the growth potential is clear. Indeed, it might be more important to address the means (organisational, economic, educational etc) by which new technologies are applied to the needs of the elderly infirm than to concentrate on the technologies themselves.

Smart houses (ie housing for elderly or disabled incorporating special IT /communications systems, remote monitoring equipment, and improved physical design or materials) were highlighted as a further growth area at the Belfast workshop.

## Innovation in pharmaceuticals

Our expanding knowledge of molecular and cellular biology is continually presenting opportunities for new therapeutic products - but do we need new skills to exploit them? This area was discussed at the Cambridge and Manchester workshops, and there was agreement that new delivery methods, and improved techniques modelling structure, function and interactions of biomolecules, and rational design would be important for competitiveness. However, rational design and modelling will complement, rather than replace, conventional screening methods and combinatorial libraries. Expertise and innovation in these latter areas will continue to be important in improving R&D productivity in the face of cost pressures. There is also strong "market pull" for innovation in toxicological evaluation, perhaps based on modelling, to improve productivity and safety, and reduce animal use.

Other areas highlighted as particularly relevant to the pharmaceutical sector included:

- growing opportunities for use of robots (or automation in general) in repetitive R&D tasks such as sequencing, screening libraries, or screening bioactive compounds
- use of immunological knowledge to develop therapeutic antibodies, new ways of targeting drugs, or technologies for tissue engineering / transplantation .

## Information Technology and communications in healthcare

Medium-term programmes for developing basic IT systems for medical records and other basic information are well under way in most developed countries. As these near completion, and as the price and power of the technology continues to improve, further opportunities will emerge. Participants highlighted three broad areas for the longer term:

- Telemedicine and telematics (including transfer of records, data and images and remote monitoring, consultation, or manipulation).
- Use of information technology to support evidence-based medicine and technology evaluation by accessing records of diagnosis, treatment, and outcome on a large scale. This may also be important in improving the productivity of clinical trials and other aspects of pharmaceutical R&D.
- Systems to inform and support clinical decisions, by presenting relevant information on prognosis, epidemiology, or treatment options, and analyzing/interpreting diagnostic data.

The trends are to some extent synergistic, and will be strengthened by improved communications infrastructure and greater computer literacy.

## Other areas

Apart from these common themes, a diverse range of topics were debated at individual workshops.

**Biosensors** were discussed in some depth at the Cambridge workshop. It was agreed that the rate of product development in the UK might appear disappointing, but, the UK accounts for two out of the six products developed worldwide. The potential market is vast, but development is likely to be slow, as the technology is complex and multidisciplinary, and application-specific. Markets are fragmented, and products are often competing as substitutes.

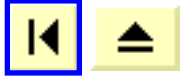
**Diagnostics** were mentioned as an area where patterns of use may change radically, with greater emphasis on combining diagnosis and treatment (eg in "smart" drug delivery systems) and greater integration of diagnostics with IT systems.

Other areas discussed included: demand and technologies for chiral production; opportunities for exploiting knowledge of cell growth and development in tissue engineering and transplantation or new therapeutic targets; biomaterials; medical engineering; minimally invasive surgery; nutrition; improving the quality and impact of diet / lifestyle information provided to the public; and psychology/cognitive sciences. Several participants also commented they would have liked to see more emphasis in the panel's work on the broader economic and market issues, and in particular on: economic factors that prevent current knowledge being applied in health care; pressure on pharmaceutical industry margins from price control and generics; and health care markets in rapidly emerging economies and other developing countries.

## 7. Workshop opinion: infrastructure for science and the exploitation of science

Turning to the broader factors affecting the UK's ability for scientific innovation and exploitation, participants at all five workshops highlighted the same key issues:

- Public understanding of science. While schools science education may be improving, the UK remains a country where the majority have little understanding of science. This tends to lower the status of science, promotes suspicion and distrust, and makes it harder to achieve informed discussion of medical or environmental risk.
- Science education. Tertiary and post-graduate scientific education needs to be more broadly based, with greater disciplinary mixing. Better education, however, must be coupled with better career structure, and better prospects of rewarding jobs, to attract the best graduates into post-graduate education.
- Technology transfer from academia to industry is still not good enough. Attitudes, communications, and organisational inertia are seen as the main problems. Solutions proposed include greater career flexibility between academia and industry, user-friendly "technology incubators" and strengthened university technology transfer networks.
- The financial environment is hostile to technology - based SMEs. In addition, within Universities there is seldom support (financial or otherwise) to take promising ideas far enough to appraise their commercial value.
- Support for the academic science base. There was a perception that due to rising costs, and tight controls on public spending, research conditions in university laboratories are falling behind those in other countries in many respects, and particularly in terms of standards of equipment and facilities.



## ANNEX 4

### DISCUSSION PAPERS

# A: FINANCIAL FACTORS INFLUENCING INVESTMENT IN NEW TECHNOLOGY

*Dr Hamish hale*

During the past fifteen years, substantial investments have been made in biotechnology and healthcare technology. In this period more than 1,500 new companies have been founded in the USA and approximately 150 in the UK. However, a much higher proportion of the USA companies are now publicly quoted than is the case in the UK.

Financing such companies falls into four categories:

1. Seed Financing
2. Start Up - Expansion Financing
3. Flotation Financing
4. Post-Flotation Financing

#### 1. Seed Financing

This is the most difficult. Relatively small amounts (£50,000-£100,000) are needed to set up an office and a small laboratory and pay the expenses of one or two people to carry out initial work to prove the utility of the concept and draw up a business plan. The risk is too high to attract bank debt financing and the investment is too small to attract venture investors. Some support to finance market research and technical development can be obtained from the DTI or regional authorities, but the lack of resource is a strong deterrent to any entrepreneur.

#### 2. Start Up - Expansion Financing

Then a concept has been reduced to practice and a business plan has been prepared and a small group of managers, usually one technical, one financial and one commercial, have committed themselves, then Venture Capital Funds will usually finance a good plan with good people. Anything from £500,000 to £5.0 million may be invested at this stage.

High technology companies usually take three to five years, or longer, to get their products into the market and as scientific research and development is expensive, they will consume around £15.0-20.0 million during this period. This money is provided through several financial rounds by Venture Capital Funds.

### 3. Flotation Financing

Up until two years ago it was not possible to float a high technology loss making company on the UK stock exchange. Since then approximately fifteen such companies in the life sciences sector have been floated. Flotation or corporate acquisition or merger are the only routes by which the venture investor can realise investment. Thus, in order to encourage early investment, the process of realisation by flotation must be encouraged.

### 4. Post-Flotation Financing

Up until the time of flotation, the decision to invest is based on the expectation that the novel technology introduced by the company is going to create a commercial opportunity and thus substantial future profits and an increase in the equity value of the company. This expectation still exists and drives the flotation process, but post-flotation, the much broader investor base, with a lower technical understanding of the company, expects profits to appear in the near future.

A variety of factors influence the investors involved in these four stages.

Seed financing of a "brown field" company entails finding money from academic institutions, banks, government agencies, "Business Angels" and relatives of the entrepreneur. Major factors influencing the ability to get through this stage are the high cost of filing patents at a time when their utility is not clearly defined. The high expense of leasing laboratory and office facilities to allow essential work to be carried out, the difficulty of academic technical transfer offices in covering the wide range of technical expertise in a major institution (eg. from microbiology through genetics, to electronic engineering to information technology) and also the unrealistic expectations, due to lack of experience, that academic institutions have for the payments made to them for intellectual property rights by the embryonic company. Some regional university concentration and specialisation of technology transfer offices must increase the efficiency of their activities. "Business angels" (high net worth individuals) may help finance the company at this stage, but their timescales and investment expectations are usually quite different from those of the venture fund managers who will be supplying funds at the next stage of the company's development. The "angels" expect a quicker return and are usually not able to put up the large sums of money required to finance the company and maintain their equity share.

Suggestions for helping these early stage companies are to lower the cost of leasing facilities, reducing any up front payments for licences on intellectual property rights, incentives to allow academic entrepreneurs to spend 100 per cent of their time on the company activity for a relatively short period, ie. six months, getting MBA students to help in the preparation of business plans.

Once the seeds have sprouted and there is a "green field" company, then the requirements for its expansion are full time commitment from the managers and removal of the company activity from the academic environment. This will require developing policies that will permit earlier movement of staff from universities and companies and vice versa. Investment by several major venture funds experienced in the commercial sector of the technology is essential and creation of financial

mechanisms to reduce the fixed overhead of the company are desirable. Any means of reducing the high cost of leasing facilities in the UK is essential. Science parks are created to make profits of the property developer is to be encouraged. Companies at this stage of development frequently obtain finance in the form of development contracts or as equity from major corporations operating in the commercial sector with which the young company is involved. These corporations pay tax. The young one does not and although it can carry its tax losses forward until it gets into profit, this does nothing for its cash flow during its expensive stage of product development. If a tax credit note recognising the annual losses of the company could be negotiated and used as a tradable security, then the loss making company could sell it to the profit making corporation to raise funds. This would create an incentive to the corporation which would reinforce its interest in supporting the technology in the company.

The creation of Venture Capital Trusts and the Enterprise Investment Scheme provide encouragement to the investor by providing 20 per cent tax allowance on money going into a new company, capital gains tax (40 per cent) relief on realisation of investments of up to £100,000 if held for five years, and rollover relief from money moving from one company to another. The 20 per cent investment relief has to be traded against the lack of dividends in such companies for a period of five to ten years and rollover relief is not attractive if the investor is looking for realisations to provide capital for spending rather than investing. Capital gains tax in the UK is much higher than in any other sophisticated country. It is a severe deterrent to the entrepreneur and the investor and its yield to the Inland Revenue from realisation in new high tech companies is vanishingly small.

Flotation of a company on the UK stock exchange is governed by rules laid down by the exchange. In the last three years these rules have been modified to allow companies without a three year profit record to be quoted on the full exchange. Approximately fifteen life science companies have taken advantage of the change in rules to become publicly quoted companies. The rules still act as a deterrent to the venture investor. They state that even though the venture investor has supported the company for five to seven years prior to flotation, when the company is floated then the investor will be stopped from realising his investment for six to twenty-four months after the flotation. The purpose of the rule, to prevent dumping of the shares into the market immediately after the flotation, is irrational as all that it does is postpone the theoretical dumping until the end of the "lock-up" period and at the same time reducing the number of shares available for trading by the broker. There are also several other guidelines which show a lack of understanding by the Stock Exchange of the nature of these companies.

Post-flotation the main problem influencing trading in the shares and the company's ability to raise money from investors is the relative novelty of the life sciences sector, apart from the major pharmaceutical companies in it, and the lack of understanding of it by the financial analysts. So far no new company has made a major breakthrough in new product introduction with a substantial increase in product sales. This is a reflection of the ten to fifteen year timescale that it takes a high technology company to go from start up to profit generation. Private investors are not prepared to exchange loss of dividends for high capital gain when they are going to have to pay a 40 per cent tax on that gain. The creation of a European equivalent of NASDAQ (National Association of Security Dealers Automated Quotations) may ease share trading problems as it would increase the number of quoted companies and create a sector large enough to arouse the interest of the investment analysts.

Pervading the entire high technology entrepreneurial ethic is the national attitude towards science and its utilisation in improving economic performance. At school, children are bombarded by the environmental and anti-'big' science lobbyists. They are constantly told of the evils of chemical pollution, nuclear pollution, animal experimentation and catastrophe theory. They are never told that

science means progress, means commercial opportunity, means income, means tax revenue, means improvement of the quality of life. Also neither school children nor university graduates are taught anything about the economics of business and government. It is all about taking rather than giving. The educational system must change to produce a positive attitude to science and to its utilisation for economic and social improvement.

## B: THE INTERFACE BETWEEN HEALTH & LIFE SCIENCES AND INFORMATION TECHNOLOGY & ELECTRONICS

*Professor Chris Taylor*

### 1. Background

Healthcare consumes a large slice of GDP in most developed countries. Information Technology has the potential to increase the quality and decrease the costs of this provision. Equally the healthcare market represents an important business opportunity for the IT and Electronics industries.

This document is the result of liaison between the Foresight panels for Health & Life Sciences and Information Technology & Electronics, it aims, briefly, to identify the healthcare opportunities and the technical challenges they present. Sources of input include the "IT in Medicine" section from the draft report of the Health & Life Sciences panel (6 December 94); the IT&E discussion of technology/market opportunities July 94), a lengthy document from Dr Alan Rector (25 November 1994) which discusses some aspects of IT in healthcare, the output of an EPSRC workshop on Medical Informatics attended by currently funded academics, the NHS and industry (8 December 1994), and a discussion (6 December 1994) between Professor John Fox (Health & Life Sciences) Professor Chris Taylor (IT&E) and Declan Mulkeen (Health & Life Sciences). A reasonably consistent view emerged, and all the important issues are summarised below.

It is clearly a matter for the two panels to establish priorities and make recommendations. It seems desirable, however, that in considering possible developments the IT & Electronics panel should take into account relative importance as perceived by Health & Life Science and Health & Life Sciences should take into account technical feasibility as perceived by IT & Electronics.

### 2. IT in healthcare

IT is already used widely in healthcare delivery for relatively straightforward 'book-keeping' activities. It is assumed that this trend will continue, without the need for any significant advances in IT. There are, however, a number of areas where predictable improvements in the price and power of computer systems, and in communications technology will create the opportunity for more advanced medical information systems. Often, fundamental advances in IT will be required to exploit these opportunities. Key areas are as follows:

**Telemedicine** includes remote monitoring, remote consultation (doctor-doctor and patient-doctor), remote intervention and virtual reality. The necessary communications infrastructure is currently being put in place though there are issues of security and confidentiality. Some simple applications are already practical and may soon enter use in some specialist areas. Systems with more local intelligence than those currently available will be needed before widespread use is possible. Issues of integration with other healthcare information systems and with other forms of service provision (and training) have yet to be addressed.

Monitoring and control includes intensive care anaesthesia, and artificial organs. Differentiated from telemedicine by absence of telecommunication and by closer interaction with expert staff. Intelligent IT systems are becoming practical for some applications (eg intensive care) but others (eg closed loop anaesthesia) are beyond the scope of current technology and need new advances in IT. The UK has relevant academic and commercial strengths (eg in neural networks) which have yet to be fully exploited in this domain.

**Image and signal interpretation** includes storage, manipulation, data-fusion and interpretation of images (and other signals). Worldwide there is a growing demand and technical capability for non-invasive imaging using MRI, ultrasound and other non-ionising modalities both for diagnosis and planning/monitoring treatment. The UK has significant academic strengths but exploitation has, in the past, been limited by the relatively weak instrument manufacturing sector. Improved international alliances and the growing importance of software for signal analysis and interpretation will lower this barrier; the UK is well placed to exploit these opportunities.

**Decision support** includes systems to provide information, analysis or options to assist in organising investigations, diagnosis, planning therapy and organising treatment plans. There is a close link with evidence-based medicine. The role of a decision support system is to provide the clinician (and other healthcare staff) with information on history, methods of investigation, diagnosis, prognosis (including genetic), trials and studies and treatment options relevant to a particular patient. Such systems will thus represent an essential complement to other forms of medical IT. Meeting this demand will involve long-term research into computational methods and both organisational and behavioural issues. These areas are academically strong in the UK though the commercial base is weak.

**Rehabilitation and enablement** includes smart prostheses, methods of rapid communication (interpersonal and man machine), and physical aids all for the disabled. With the ageing population disablement will become an increasing problem over the next few decades and labour-intensive solutions will become impractical. Some of the problems are mechanical but intelligent IT systems have the potential to make a huge impact. This will depend, however, on significant advances in the technology. The existing industry is small and fragmented worldwide but, given suitable products, this could become a new and important consumer market with significant impact on quality of life.

**Intervention** includes robotic or robot-assisted surgery, image guided surgery and conformal radiotherapy. Mechanical and conventional electronics issues are important, but advanced IT is essential to adapt systems to individual anatomy and pathology. It is difficult to assess the acceptability and importance of such systems at present.

### 3. The challenges for IT & electronics

IT applications in healthcare have had a chequered history. This is largely because, despite the obvious potential, the technology has often been inadequate. In part these limitations have been due to the shortcomings of computer hardware and communication systems. However, immature software technology and limited understanding of users' needs have contributed significantly to inhibiting progress. The price and performance of computing and communications hardware have reached a point where they no longer (or will not soon) impose any limitation. There is also a greatly improved understanding of the complex organisational structure (both formal and informal) of health services and of strategies for deploying IT effectively, though further research is required in this area. There are, however, major software challenges which must be met if the potential of IT to transform much of

healthcare delivery is to be realised. The fact that software is the essential enabling technology presents an opportunity for UK industry, which has traditionally been weak in hardware manufacturing to gain a share of this lucrative market. The important feature of the next generation of medical information systems will be their ability to display intelligent behaviour. Six key areas of generic software technology can be identified.

**Human factors.** The way people interact with IT systems is central to their effectiveness. Issues are forms of interaction (speech, handwriting, gestures), integration of different information processing functions, cooperative style of working, organisational and behavioural issues.

**Knowledge representation.** Medicine is characterised by its reliance on diverse and complex forms of knowledge. There is a fundamental need to develop an underlying theory and effective methods of representation for medical technology, anatomy, pathology, treatment protocols, arguments and so on.

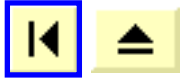
Systems which learn. Medical information and its applications are sufficiently complex that it is unrealistic to conceive of systems which are designed in every detail. Systems which self-organise and learn have the potential to overcome this problem and will become increasingly important.

**Data and knowledge mining.** As more information becomes available over networks (eg in an evidence-based medicine context) it will become impossible for it to be managed directly by humans. Systems which seek out and interpret information relevant to their current tasks will be important in realising large-scale information-based healthcare systems.

**Image and signal interpretation.** Images and signals are an expensive and increasingly important source of medical information. Methods which can interpret images by applying knowledge of anatomy, pathology and function will be essential in making optimal use of the information and in content-based retrieval of relevant information.

**Modularity and scalability.** Major problems with existing medical information systems are the inability of different subsystems to interwork and the monolithic nature of much design which leads to inflexibility and failure to scale-up. New software methodologies will be required to build very large complex systems of modular design.

**Safety critical design.** The uses of medical information systems are often life critical. It is thus essential that design methodologies are used which lead to provably safe systems. Although this is a growing field, existing methodologies are inadequate to deal with very large complex systems.



## ANNEX 5

### INITIAL HYPOTHESES

(as used in the panel's consultation work)

#### Introduction

The ten hypotheses that follow are based on suggestions from previous studies, from ideas gathered in a preliminary survey of individuals working in health care, industry, and academic research, and from panel members themselves. The hypotheses are not intended to present a balanced or comprehensive view of the issues. Rather they are intended to provide a starting point for consideration and discussion - in some areas they are deliberately provocative.

#### Hypothesis 1

**The increased understanding of the genetic and environmental origins of disease will result in the widespread application of probabilistic medicine at an individual level.**

**1.1** Current public health measures, and preventive medicine, are based mainly on knowledge of factors influencing disease in large populations. The fact that risk is not individualised limits the public compliance with preventive measures. It is possible to screen individuals, in quick, cheap and convenient ways, for factors predisposing to disease but the range of factors is very limited. This situation may change dramatically over the next twenty years.

**1.2** Genome research already offers the possibility of screening for a wide range of single-gene disorders, and some genes relevant to multifactorial disorders, familial cancers and degenerative disorders. There is every reason to expect that the next decade will see the identification of more widespread inherited factors predisposing to common forms of cancer, heart disease, mental illness, birth defects, dental disease and others. At the same time, we are improving our understanding of the links between genetic polymorphism, metabolism, environment, early development and lifestyle in the epidemiology of multifactorial disease.

**1.3** It may become practical for general practitioners to screen all patients for genes predisposing to common diseases, and combine genetic and epidemiological information to judge the level of risk. Rational healthcare plans - based on preventive measures or early detection - could then be selected using quantitative outcomes information.

**1.4** The main beneficiaries of screening and preventive measures are likely to be those in mid-life - at least initially. Among the elderly the complexity of the interplay between ageing, genes, environment and lifestyle may reduce the value of the approach, and the elderly may be less able to alter lifestyles.

**1.5** This approach to primary care would be synergistic with:

- (a) improvements in nucleic acid science and diagnostic technology permitting much cheaper, more accurate and reliable screening methods which could be widely used outside specialist laboratories
- (b) further development in the skills of auxiliary medical staff/ service organisations to allow them to take on more of the work of screening, counselling, and implementing preventive care plans.
- (c) improvements in biomedical computing (see Hypothesis 2) and evidence-based medicine
- (d) development of:
  - preventive pharmaceutical/nutritional supplements for individuals predisposed to major illnesses
  - "designer" foods tailored to the customer's genome, and the emergence of "life style modifying" therapies and companies

**1.6** Key questions in this area are:

- (a) Are current methods of lifestyle alteration effective enough? Will lifestyle alteration, and other preventive measures be more effective when based on individualised risk? If not, how else could effectiveness be improved?
- (b) Will lack of scientific knowledge and understanding among members of the public limit the value of the information?
- (c) How will insurers and employers interpret and use the new information available?
- (d) Widespread screening will be costly in itself, and will force health professionals to spend more time with healthy individuals. Even if the benefits are commensurate with the cost, is society willing to pay for it as part of a national health service?

## Hypothesis 2

**There will be a rapid penetration of information technology into health care and the life sciences - not only for data management, but also as a tool for insightful analysis, modelling, and interpretation**

**2.1** The continued expansion of knowledge, the growing desire to control the efficacy and cost of treatment, and the increasing complexity of diagnosis and treatment will tend to expand the market for advanced information and communication systems in health care and the life sciences. Within the health sector, opportunities might include:

- (a) systems for supporting the management of multidisciplinary treatment regimes
- (b) systems and databases to supply physicians with focused, relevant information or advice, to assist in diagnosis, and selection of the most appropriate treatment protocols

- (c) systems to support interpretation of genetic and epidemiological information on predisposition to disease, and suggest possible courses of action
- (d) systems to collect information on illness, health processes, outcomes, and pharmaceutical and epidemiological information at local and national levels, and assist in analysis
- (e) remote access to medical records and images using networks or "smart cards" carried by patients

## 2.2 Opportunities to use IT to speed progress in R&D will include

- (a) systems to assist researchers to analyse and compare gene sequences, and model their products
- (b) assisting investigators in developing integrated models of very complex biological systems - including cellular / physiological control systems, and ecological systems
- (c) systems to extract selected information from publication databases or novel scientific knowledge systems.

**2.3** Most medical applications could be achieved without radical advances in hardware or software design. R&D applications and expert systems might require novel software design - perhaps based on neural networks in some specialised areas. Where there are no patentable or exportable products, bio-medical computing is likely to develop as an important UK service industry, concentrating on collecting high quality information, refining the information to suit physicians', scientists' and policy makers' needs, and designing software to permit rapid, flexible access, and educating users.

## 2.4 Key questions in this area are:

- (a) Will users resist innovation, preferring to collect and analyse information themselves? Will there be resistance to the devolution of more specialist clinical knowledge / expertise to GPs and other health workers in the community?
- (b) Will greater use of IT have to be accompanied by greater standardisation of terminology, procedures, and protocols?
- (c) Will the rate of uptake of new technology within the NHS slow development of this sector in the UK?
- (d) Who will develop and manage systems to capture and interpret the expanding range of information on heredity, environment, disease, and outcomes?

## Hypothesis 3

**R&D into new therapies will be targeted at major innovations in the treatment of the principal disease areas, with small markets receiving relatively little attention. Cost / benefit analysis will**

## **be central to product assessment and development.**

**3.1** In response to the high cost of R&D, and health services' demands (worldwide) for cost-effective therapies, pharmaceutical companies will tend to target efforts towards radical advances in treatment for the major diseases of the developed world, such as asthma, dementia, or stroke, and in particular the autoimmune and degenerative disorders. Of the areas with a truly global demand, vaccines and contraceptives may win strong investment. There will be relatively little investment in incremental development of existing therapies.

**3.2** More tightly focused R&D portfolios within the pharmaceutical industry may tend to increase the number of "orphan diseases", where, despite a clear social need, markets are limited, or involve a high degree of risk. There will also be unmet demand for improvement in low-tech devices and appliances where small markets and slim profit margins discourage investment.

**3.3** Collaboration between businesses and health services will become more important in product assessment. There will be demand for new clinical trial methodologies, incorporating cost / benefit comparisons with existing treatments, and better outcome measures.

**3.4** The current rapid rate of progress in genetic manipulation, protein structure/function, protein / antibody engineering, carbohydrate biology, and cell biology offers exceptional opportunities for systematic, targeted development of new therapies in these areas. Improved technologies for delivering and targeting protein drugs (and genes) will be particularly important. Instead of being mass produced, the new therapies based on genes, cells, and tissues may need to be designed and prepared to suit individual patients.

**3.5** Key questions in this area are:

- (a) What sort of businesses or organisations will deliver individualised gene, cell and tissue based therapies, and what will be their relationship with the physician?
- (b) Where there is a clear social need for new products, but high risk or limited markets discourage investment, how should the Health Services stimulate development? Should the Health Services become directly involved in development or production?
- (c) How can health care purchasers influence innovation?
- (d) How can the UK make better use of national strengths in clinical medicine, research and evaluation to support innovation in medical technology against increasing international competition?

## **Hypothesis 4**

**Gene therapy, protein / antibody drugs, and cell or tissue-based therapies will account for many of the principal therapeutic innovations in cancer, degenerative diseases, and autoimmune diseases.**

**4.1** Small scale trials of gene therapy are already under way, and it appears likely that effective treatments will be available for common single gene disorders (cystic fibrosis, sickle cell) and

conditions predisposing to cancer (familial adenomatous polyposis) within 5 - 10 years. Gene transfer may also become widely used in treating cancer (by expressing toxins or modifying immune responses), immune and inflammatory diseases, and in tissue implants/explants.

**4.2** Exploiting the full potential of gene therapy will depend not only on the identification of new genes, but also on improving basic technology in a number of areas:

- (a) new vehicles for gene transfer, particularly artificial (non-viral), efficient, tissue specific delivery systems - often based on multidisciplinary approaches
- (b) translational and transcriptional control, down-stream processing, and the effects of introducing anti-sense sequences.

The rate of progress will not be limited by the acquisition of genetic knowledge, but by the difficulty of integrating the structure and function of the gene products with cell and tissue physiology. Integrative biological research currently suffers, in the UK and abroad, from being relatively unattractive to researchers, but will be key to exploiting current genome research.

**4.3** Gene therapy for multifactorial and multigene diseases will be slower to develop. Not only are the diseases themselves more complex, but the availability of alternative treatments and preventive measures will mean gene therapy is unattractive unless costs are low and risks negligible.

**4.4** Apart from gene therapy, the most dramatic changes in therapeutics will be driven by synergistic trends in four generic technologies.

- (a) the expansion of gene sequence information, together with IT systems for screening sequences and modelling tertiary structures of their products will provide a new route to discovering therapeutic molecules. The same technologies will greatly accelerate research into cell and tissue control systems - provided integrative approaches receive adequate emphasis and funding.
- (b) improved understanding of protein and antibody structure and function, and the capacity to design and manufacture customised structures. Opportunities will arise not just from understanding the primary functions of the protein, but also how proteins can be incorporated into membranes, how transport within the cell can be controlled, and the basis of self-assembly.
- (c) developments in drug delivery technologies will offer numerous new possibilities, and will be particularly important in the administration of protein drugs. It may also become easier to minimise side effects on complex systems by delivering drugs to the surface of specific cell types or regulating drug release in response to the patient's condition.
- (d) better understanding of the mechanisms controlling cell growth, differentiation, tissue development, and cell death, offering wider opportunities for the use of cells and tissues in treatments.

**4.5** Areas that are particularly promising, and where social need, scientific and technical advances, and commercial opportunity coincide include:

- (a) immunological and inflammatory disorders (such as asthma and the autoimmune diseases) where a better understanding of activation and regulation of the immune response offers possibilities for drugs based on mediators and cytokines, or antigen and antibody therapies.
- (b) degenerative diseases such as dementia and Parkinson's disease
- (c) cancers (especially solid tumours), where a very wide range of approaches have been proposed, including immune therapies, antimetastatic agents, gene therapies, and therapies based on knowledge of the key mutations in individual tumours.

**4.6** The opportunities offered by improvements in the understanding of cell and tissue growth and differentiation will be very diverse. They may range from improved wound healing to tissue implants in endocrine, immune or metabolic disorders, grafts of cultured cells, and cell-based artificial organs.

**4.7** Key questions in this area are:

- (a) Is the UK well placed to exploit scientific developments in this area?
- (b) What is the best way to manufacture products for gene therapy and control their quality, safety, and efficacy ?
- (c) Does the UK need to foster or co-ordinate integrative biology to facilitate exploitation of the genome?
- (d) Internationally, will germ-line therapy be widely practised?
- (e) Will the expansion in genetic information mean competitiveness depends much more on expertise in molecular engineering, efficient manufacture, and targeted delivery technology; and less on the discovery of new active agents - which will become increasingly easy?
- (f) Is the UK strong in basic research into the cellular and molecular processes of the most important systems and diseases?

## Hypothesis 5

**Current diagnostics and instrumentation technologies will evolve towards applications outside of specialist centres, towards uses in local clinics and in the home.**

**5.1** Demand for diagnostics is expected to continue expanding for some time, despite cost pressure on health services. Customer pressure will increase demand for fast, non-invasive, "bedside" diagnostics, or for cheap, noninvasive devices linked to communication networks to permit monitoring in the home or as patients go about their daily lives.

**5.2** Technological improvements in genetic diagnosis, recombinant antibodies, and biosensors will broaden the healthcare markets. The most attractive technologies in instrumentation will continue to be those offering real-time, continuous, minimally invasive monitoring. Current research in NMR and imaging techniques using radioisotopes offers the possibility of improvements in resolution, though

less well established methods such as in-vivo spectroscopy could be more effective in some applications.

**5.3** Animal health applications will also broaden, driven by public concerns about welfare, reduced tolerance of pharmaceutical residues in food, and by the increasing mobility of livestock, and diversification into new species and husbandry methods. Public attitudes will also create opportunities for environmental monitoring equipment and robust biosensors, and for new measures and models of toxicity.

**5.4** The current technologies with the greatest potential for development include:

- (a) automation and image analysis: there is obvious potential for replacing many of the existing manual procedures carried out in routine laboratories.
- (b) antibody - based assays: monoclonal antibodies will eventually be replaced by custom-designed recombinant antibodies, offering improved affinity or avidity, and better performance in enhanced detection systems (chemiluminescence etc). The identification of genes predisposing to disease, or mutations involved in particular cancers will increase demands for antibody assays - in some areas screening for the gene product may prove quicker, more reliable, and cheaper than screening for the gene.
- (c) PCR: PCR is already in limited routine use in detection of microorganisms, and there are numerous potential applications in medicine, food sciences, and environmental sciences, but the technology is not yet suitable for routine use outside specialist laboratories. There is a significant market for improved techniques, though the Roche patent may tend to slow commercial development.
- (d) genetic sequencing: advances in knowledge of single gene disorders, genetic predisposing factors, and the molecular biology of cancer will generate large potential markets for rapid automated sequencing procedures and sequence recognition, and there has already been a lot of international investment in this area.
- (e) biosensors: biosensors are a rapidly expanding field, with a number of products about to enter the commercial scene. The technology is still at an early stage, and improved knowledge of the interactions between proteins and inorganic or inert surfaces will expand the range of applications.

**5.5** Despite a history of technical innovation in the UK, we do not have a significant presence in the global biomedical equipment or diagnostics markets. There are some strengths - in low-tech appliances for instance and UK manufacturers of in vitro diagnostics compete well on the home market. The global market tends to be dominated by large multi-national firms carrying very wide product ranges, making it difficult for new companies to penetrate. Some UK SMEs are now forming strategic partnerships with the large trans-nationals, and this approach may offer the best long-term prospects for exploiting UK technical strengths.

**5.6** The key questions in this area are:

- (a) What areas of research might yield novel diagnostic technologies ?

- (b) Does the UK have strengths in the basic science underpinning the more promising technologies?
- (c) Is it possible to improve the UK's industrial position in diagnostics and imaging without a substantial transfer of resources from other sectors?
- (d) How will health services respond to the ethical, cost, and organisational issues raised by new technologies and customer demands?
- (e) Are new communication systems needed for quality assurance and interpretation needed to support decentralised near-patient testing?

## Hypothesis 6\*

*\* There are several areas - such as cellular immunology or developmental biology - where improved understanding of biological systems will offer major opportunities over the next two decades. It is not practical to cover all these in depth in this document. Cognitive sciences are discussed below, partly as an exemplar, and partly because the applications are of a very different nature to those in other areas.*

### **As social needs change, an improved understanding of human cognition will find new applications outside of mental illness.**

**6.1** Current trends in research into human cognition, coupled with greater integration between cognitive psychology, basic neurosciences, and theoretical studies, offer good prospects for advances over the coming decades. Developments in our understanding of cognition could have a pervasive impact beyond their obvious value in dealing with the major mental illnesses:

- (a) by improving our ability to cope with, or alleviate, variations in cognitive performance within the "normal" range.
- (b) by improving our understanding of the developmental determinants of performance.
- (c) by helping individuals to cope with extreme demands (such as recovery from brain injury) or permanent deficits.

**6.2** The range of opportunities includes:

- (a) understanding the biological and psychological processes involved in attention, stress, and fatigue and diurnal variation. This could offer opportunities in improved job or equipment design, preventive training, and targeted nutritional or pharmaceutical interventions.
- (b) understanding the influence of prenatal and childhood activity and experience, disease, and nutrition on mental performance in adults.
- (c) understanding genetic determinants of variance in intelligence and other functions.

- (d) understanding the causes of the "normal" decline in cognitive function with age - offering the possibility of either preventative or palliative measures.
- (e) design of expert systems to help "mind-workers" overcome weaknesses inherent in the human mind, such as coping with multiple tasks.
- (f) understanding the relationship between memory, learning and synaptic plasticity could, perhaps allowing remediation of memory loss in old age, or ways of enhancing learning in rehabilitation or childhood.

### 6.3 Developments in understanding of cognition would be synergistic with:

- (a) improvements in software for computer modelling and for expert systems.
- (b) advances in the rational design and targeted delivery of drugs.
- (c) improved design of artificial sensory prostheses and tissue grafts.

**6.4** Social and cultural attitudes will be critical in determining how new knowledge is exploited. Particularly in areas such as child care, genetic predictors, or performance enhancing pharmaceuticals, there will be justifiable suspicion of any innovations. However, growing awareness of the problems of cognitive decline in the elderly, and of addictive problems, environmental toxins, and stress, may make society more receptive.

### 6.5 The key questions in this area are:

- (a) How will society deal with the ethical and legal issues surrounding knowledge of genetic determinants of mental function, and the ability to modify cognitive function?
- (b) What organisations will provide counselling and other non pharmaceutical interventions for psychological and performance problems within the "normal" range? Will we see the development of employer - funded schemes, as in the USA ?
- (c) What scope is there for developing pharmaceutical agents for reducing dysfunction and boosting "normal" performance?
- (d) Is the science base strong enough, and well co-ordinated enough, to support developments in this area?

## Hypothesis 7

**Genetic manipulation will produce wide ranging opportunities for designing plants as sources of enzymes, therapeutics, polymers and fuels, products that cannot be produced by conventional syntheses, improving yields and applications offering environmental benefits.**

**7.1** The UK has a strong research base in crop plant development, disease control, and strain

development, and strong companies servicing the agricultural and horticultural sectors. Genetic manipulation offers diverse possibilities, which can be loosely grouped into:

- (a) new products - such as oils, starches or proteins for food use, pharmaceuticals or enzymes and biological production of polymers or fuels. The ability to produce animal products, such as antibodies, in crop plants is particularly promising; as are industrial feed stocks for biodegradable polymers, and precursors requiring reduced downstream processing.
- (b) altered properties and structure of plants - such as food with better characteristics, lower allergenicity; crops that are easier to harvest and whose pods do not shatter; bioremediation; or modified plant fibres.
- (c) efficiency and yield (including nutrient uptake).
- (d) resistance to pests, disease, or extreme environmental conditions.

**7.2** The technology for producing transgenic crop plants is well established, and expertise in gene isolation and manipulation is now reasonably widespread. The rate of progress is limited by lack of basic science - and manpower - in plant biochemistry, physiology, and soil chemistry/ biology, the skills base for which is widely scattered throughout the U.K

**7.3** Environmental issues will be one of the major driving forces in plant research and development over the next twenty years. Environmental pressures will generate demand for crops able to maintain yield with less use of "artificial" pesticides and fertilisers, for complex biochemicals, materials and fuels from renewable sources, and for bioremediation. Set aside policies, in particular, may determine the opportunities for using land to produce industrial feed stocks.

**7.4** The genetic and biochemical expertise needed to improve yields will be important both in the UK, and in the developing world. In the developed world, current over-production means yield improvement will be most relevant in new plant products. Markets for crops tolerant of extreme conditions, will lie mostly in the developing world - in the developed world there is little incentive to grow crops in marginal conditions though the UK science base is not particularly strong in this area.

**7.5** The plant biotechnology sector as a whole faces several constraints:

- (a) seasonal growth.
- (b) low agricultural prices.
- (c) public lack of understanding, and resistance to, genetically manipulated food.
- (d) concern over hazards presented by release of modified organisms, and the difficulty of regulating novel technologies effectively without stifling innovation.
- (e) "development gaps" - in particular the difficulty of finding funding and facilities within the academic sector to scale-up innovative processes and demonstrate commercial value.
- (f) uncertainty over the strength of IPR legislation outside of the EC discourages investment.

The key questions in this sector are:

- (a) What environmental and agricultural policies would promote the development of internationally competitive plant technology?
- (b) What research is needed to allow faster, rational risk assessment?
- (c) Is the UK's gene technology adequate to support development? How can the development of biochemical and physiological knowledge best be co-ordinated with industries needs?
- (d) How can the UK best strengthen the weaker areas within the science base? Should it?
- (e) Could changes in intellectual property legislation and agreements promote R&D investment in this area?

## Hypothesis 8

**New immune therapies, gene therapies, protein drugs, tissue engineering, and diagnostics, will require novel synthetic processes if their full potential is to be realised.**

**8.1** Over the next two decades, manufacturing centred on the health and life sciences will translate more and more of the recent developments in biology into safe and efficient commercial processes. Expertise in relevant, novel, manufacturing technologies must be developed concurrently with the science if the UK is to be competitive.

**8.2** The UK is strong in the manufacture of conventional pharmaceuticals: it has not yet embraced large-scale manufacture of the new biopharmaceuticals, although there are a significant number of new small biopharmaceutical companies. Outside the pharmaceutical sector, manufacture based on life sciences is strong in the larger food, agriculture, and the waste treatment sector. However, there are fewer technology based SMEs in these areas. The academic base in training and research in biochemical engineering, food engineering, and biomedical materials is small, though recently strengthened by (inter alia) establishment of two IRCs.

**8.3** The technologies likely to be important in exploiting advances in the life sciences include:

- (a) lean and small scale manufacture: if as seems likely, future medicines are targeted to smaller sub-divisions of the population, mass production will need to be complemented by leaner manufacture, allowing economic production of drug variants. At the same time gene therapies, and perhaps immune therapies, may need to be tailored to the individual genotype / phenotype, and produced in micro-production units closely associated with the physician.
- (b) alternatives to high-dilution bioprocessing: cost reduction pressures in all sectors will demand novel approaches to overcome the disadvantages of high dilution processing, such as the need for many product purification stages.
- (c) IT in bioprocessing: a switch to computer based validation of manufacturing bioprocesses is

occurring, and will link up with greater use of computer based analytical systems in bioprocessing.

(d)

processing transgenic plants and animals: as transgenic organisms are used as sources of medicines, food, and other products, there will be demand for new manufacturing processes, or significant alterations of existing ones. Nutraceuticals - foods with defined health properties - may become increasingly important in preventive medicine, and may also demand new manufacturing technologies.

#### 8.4 Key questions in this area are:

(a)

Are there adequate links between health and life sciences research, biochemical /biomedical engineering research, and the business processes necessary for commercial development? If not, how can interdisciplinary and multicentre networks be promoted?

(b)

Given the growing power of the technology, and the likelihood of unforeseen manufacturing incidents, should a formal biohazard framework for the manufacture of biotechnology based products be laid down at this stage?

## Hypothesis 9

**New opportunities in basic research will require for new structures in the science base, to strengthen multi-disciplinary networks, broaden skills, and provide a better platform on which to base commercial collaborations .**

**9.1** The UK scientific base in Universities and Research Councils contributes to wealth creation and quality of life in three ways:

- - training and development
- - extending basic knowledge
- identifying innovative applications of science and technology.

The larger UK-based businesses look to the science base primarily as a source of state-of-the-art training and science, with product R&D mainly carried out in-house. Science base innovation is more important for small and medium sized enterprises (SMEs) - many of which are started by entrepreneurs within academia - and for the non-profit sector - medical procedures for instance. Particularly in the pharmaceutical sector, the role of SMEs and academia in the discovery of new therapies may gradually expand as larger companies change business strategies and diversify into health care provision. This will increase the importance and power of these partnerships, leading to more favourable licensing and royalty agreements.

**9.2** Despite substantial improvements over the last decade, the rate of progress in some sectors is still determined by the cultural and attitudinal barriers to effective partnerships between academia and business, rather than by technological or market factors. These barriers include the low prestige traditionally accorded to applied science, the perceived lack of reward, and lack of understanding and communication. There is still insufficient movement of scientific manpower between the business and academic sectors - partly because salaries, responsibilities and conditions are so different. Furthermore, the narrow training of doctoral students means most emerge with a limited

understanding of economic, business, and management issues.

**9.3** The science base structure may need to change to take advantage of the emerging opportunities. Many of the most promising areas of research call for multidisciplinary approaches and multidisciplinary training. Increasing worldwide investment in life sciences means larger, collaborative consortia are needed to maintain a competitive rate of progress, and to provide a suitable platform for exploitation. Running counter to this need, career expectations, academic fashions, and funding / assessment procedures tend to create imbalances between disciplines, and lack of co-operation within disciplines. There is pressure on researchers to choose areas which are academically fashionable or where good publication rates can be achieved relatively easily, over equally valuable but slower-moving areas. Competitive funding and career decisions can also encourage over diversification into attractive niches within disciplines, and to the detriment of co-operative groupings.

**9.4** Key questions in this area are:

- (a) Does the structure of the science base significantly weaken the UK's capabilities relative to key competitors?
- (b) Is the UK capable of effecting significant change in the scientific structures, skills or attitudes within a decade?

## Hypothesis 10

**Rising expectations of a better quality of life will result in a more positive attitude to health promotion, more support and advances in treatment for the disabled and to the more efficient and rational delivery of healthcare.**

**10.1** As disposable income in the developed world continues to rise, as new scientific discoveries lead to improved medical technologies and therapies and as the consumer becomes better educated on the "art of the possible" via more widely and readily available information sources, expectations for the quality of life will continue to increase. The search for an improved quality of life will embrace a variety of issues, in different countries, influenced by cultural traditions and values. It seems inevitable that possibilities and expectations will run ahead of incomes, and it will always be necessary to ration the delivery of health care according to overt, rational criteria.

**10.2** Mid-aged groups will progressively adopt a life style designed to avoid quality of life problems in later years - avoidance of smoking, healthy diet, exercise, etc - the incentive being the more widely available knowledge at the individual level of the risks run from injudicious behaviour (cf Hypothesis 1).

**10.3** In parallel with this trend, research into pre-natal and childhood factors pre-disposing to adult disease may offer even greater possibilities for preventing disease: early life may prove easier to influence than adult life.

**10.4** The quality-of-life expectations of the most disadvantaged - the permanently disabled and elderly infirm (and their overstretched families and carers) will also rise and may be increasingly backed by legislation in some countries. Their needs will always be met in part by low-tech appliances and human services. Their needs will also embrace technologies that enable them to play a more normal role in society: improved communications technologies (including cognitive and language prostheses); the

means to participate in education and leisure pursuits; remote monitoring; "smart" houses and automated environmental control. However, the most disadvantaged have little economic power, and in the UK their needs are overseen by a diverse set of organisation. There may be little impetus for technological innovation.

**10.5** Current, and worldwide trends in health services are likely to continue, leading to a progressively knowledge-based system of medical practice which is underpinned by well researched cost/benefit data. The use of clinical protocols and guidelines and other expert systems, clinical outcomes analysis and quality control procedures will become routine. A high proportion of all surgery will use minimally invasive techniques (with, perhaps, ultimately the remote use of robotics) and be carried out on a day-case basis. The number of hospital beds will decrease, hospitals will become more specialised in the services they provide (teaching hospitals for high technology health-care, district hospitals for immediate trauma care, specialised diagnosis and low-tech treatment, and community hospitals for geriatric, convalescent and terminally ill patients). More primary care will be provided by local community health-care centres using telecommunications to access off-site expertise.

**10.6** Key questions in this area are:

- (a) What steps could be taken to promote investment in technologies to improve the quality of life of the most disadvantaged?
- (b) Is the knowledge already available on which to base rational health-care delivery or will major research programmes need to be launched to provide its foundations? What will be needed by way of infrastructure to make the knowledge widely accessible and usable?
- (c) Are health services in the developed world converging on a common structure for delivering health-care? Will new health care structures require new approaches to clinical research?
- (d) How do affluence and social background affect ability to adopt healthier lifestyles? Will these factors have more or less impact on pre-natal and early experience?

**NOTE: When the Hypotheses were used in consultation, in July/August 1994, they were prefaced by a series of open-ended questions to respondents. These were:**

Questions about your field

- 1) If you could talk to someone who actually knew what the future held for your area of work, what sort of questions would you ask?
- 2) If things went very well in your area of work, looking at it optimistically, what developments might be possible within the next twenty years?
- 3) If things do not go so well, what do you see as the obstacles that might limit progress?
- 4) How could government policies and regulations help ensure the optimistic targets are achieved?
- 5) What changes would strengthen the UK's collective science, medical, and industrial base?

6)

If you were in charge of a major budget, in what areas of your field would you invest for results over the next 10- 20 years?



[Contents](#)

