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EXPLOITABLE AREAS OF SCIENCE

A Report by the Advisory Council
for Applied Research and Development

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ADVISORY COUNCIL FOR APPLIED RESEARCH AND DEVELOPMENT

STUDY GROUP ON PROMISING AREAS OF SCIENCE

On 25 October 1983, ACARD announced the establishment of a study of Promising Areas of Science. The objective of the study which was linked to the Council's role in advising Government on its Annual Review of Research (this review of the Government's total expenditure on R & D was announced in a White Paper, Cmnd 8591 in 1982), was to survey current scientific developments and advise the Council on work which showed commercial and economic promise in the medium to long term. A Study Group was set up with terms of reference outlined in the Introduction to this report.

The members of the Study Group are:

Dr C H Reece (Chairman)	Director of Research and Technology Imperial Chemical Industries plc
Mr A Best	Anthony Best Dynamics Ltd
Professor Sir Hermann Bondi FRS	Master of Churchill College, Cambridge
Mr R Cutting	Sinclair Research Ltd
Dr C Hilsum FRS	Chief Scientist, GEC Research Laboratories
Mr C S King CBE	Deputy Chairman, BL Technology Ltd
Professor J S Metcalfe	Department of Economics Manchester University
Professor D K Peters	Department of Medicine, Royal Post-graduate Medical School
Professor Sir David Phillips FRS	Laboratory of Molecular Biophysics University of Oxford

Professor G G Roberts FRS	Department of Applied Physics University of Durham
Professor J M Thomas FRS	Department of Physical Chemistry University of Cambridge

The Study Group held ten meetings over the course of the study and arranged a series of meetings with companies and organisations with major responsibilities for R & D. The report presented to the Council contains a distillation of the views of the group which also takes into account the comments of those consulted during the course of the exercise.

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EXECUTIVE SUMMARY

1. There is a thesis, widely accepted in the United Kingdom, that basic research cannot be organised to deliver economic return. The thesis is not generally accepted in other countries. They believe that science is now so important to a country's future that some attempt must be made to structure support, and achieve more effective exploitation of science.

2. This exercise is an overview gathered by the Study Group after consulting an incomplete but generally representative series of groups in the United Kingdom. It is therefore limited in depth and completeness. It is set against a backcloth study of the predictions of scientific futures in USA, Japan, France and Germany.

3. The report analyses the prospect for increasing longer term economic return to the United Kingdom of the expenditure on scientific research. It is divided into Part I - Exploitable Science - The Need for a Process, and Part II - An Investigation of Exploitable Science in the UK.

4. We believe that its value lies mainly in the conclusion that some mechanism is needed in the best interests of the country to prioritise and guide a fairly high proportion of that part of the national scientific resource paid for by the taxpayer, and to stimulate its effective exploitation to the benefit of the United Kingdom. It is recognised that the remaining and significant proportion of publicly funded scientific research should be determined by peer judgement of scientific excellence etc in the established way.

5. The study recognises that the past levels of support of UK science has been the desirable result of prosperity and that its fruits have tended to give benefits worldwide rather than to the United Kingdom. However, in the future, national economic success will be built on the foundations of scientific knowledge and capability. From this comes the challenge which we must meet - to use our considerable national investment in scientific ability for the national benefit.

6. We do not have a forum in the United Kingdom where we can manage the process referred to above. It is we believe a matter of national priority that such a forum be established.

SUMMARY OF THE REPORT

1. Countries with a major technological capability appear to have developed processes for holding debates about directions in science and technology and the associated policy. In this country, we do not have a forum in which to manage this process. In fact, we do not even have databased which allow this process to be managed effectively, and the dispersed data we have is essentially non-interactive.

2. The study we have carried out has led us to a view of the processes which could be pursued given some trust and commitment by industry and the established scientific organisations. Such an activity cannot be done occasionally, but must be a continuum with sufficient resources committed, both in quantity and time, to ensure that there is consistency of judgement.

3. We conclude that it is both feasible and desirable to create a framework for an agreed process for generating strategic exploitable science priorities.

Outline of the Draft Report

4. The study was approached by considering the economic and social activities in society and relating them to their influence on technology in order to determine the science areas required to underpin that technology. Such an approach forms the basis of our considerations and recommendations on a process for identifying exploitable science areas described in this report. The first chapter outlines the origins of the exercise and sets out the terms of reference for the study which were:

a. to report on those areas of science and specific scientific developments likely to have significant economic consequences within ten years and within twenty years;

b. to comment, as far as possible, on the adequacy of the above areas of science in the UK in terms of the technology perceived to be required in the future.

There is a clear relationship between the study, the Annual Review of

Government-funded R & D, and the Government's view on the Annual Review expressed in Cmnd 8591 that, "skillful value judgements as to allocation of financial and manpower resources are, however, needed. This will involve distinguishing between vital and dormant areas, identifying gaps, disparities and duplications, and considering the opportunity cost of relinquishing certain areas of research."

5. We consider in Chapter 2 the main issues which arise in the process of assigning promise to areas of science. We define an exploitable area of science as "one in which the body of scientific understanding supports a generic (or enabling) area of technological knowledge; a body of knowledge out of which many specific products and processes may emerge in the future". Thus the exercise is not perceived to be one of picking winners but of strategic policy aimed at creating a reservoir of knowledge out of which the, as yet unidentified, winning products and processes will emerge. An aide-memoire for identifying promise in science is presented and some rules of thumb given for minimising the inherent risk in resource allocation that opportunities might be missed and promise extinguished.

6. The issues raised by such considerations are summarised in the form of a sequence of questions, each one focussing upon a particular aspect of exploitable science -

i. Which areas of generic technology are supported by a particular area of strategic science?

ii. Has the UK the scientific resources to advance a particular area of strategic research? If not, how quickly can resources be acquired eg by changing the emphasis of undergraduate and graduate programmes?

iii. Within a generic technology what classes of new products and processes will become possible within a ten or twenty year horizon?

iv. What indicators are there of the likely costs of translating knowledge from the generic pool into marketable products and processes?

v. In which areas of existing industrial and commercial activity will the new products and processes find initial application? What advantages will they offer and how might markets respond to these advantages?

vi. How quickly might the perceived markets develop and what might be the ultimate niches of the new products and processes?

vii. What evidence is there for a foreign industrial presence in the relevant areas and what implications does this have for UK market share?

7. The approach taken in the study is described in Chapter 3. Ways in which techological forecasting and scientific assessments have been made in the past both in the privately and publicly funded R & D domains are discussed. A brief outline is given of an exercise commissioned by the Study Group with the Science Policy Research Unit (SPRU) of Sussex University on how other countries plan science and technology R & D investments. (The full SPRU study was published towards the end of 1984 in the book "Picking the Winners: Foresight in Science" by Irvine and Martin). The main conclusion of the SPRU study was that "The United Kingdom should attempt to bring the level of its long-term scientific and technological foresight activities up to that found in Japan". The Study Group considered the main reason for Japanese success in technological foresight was the total commitment to the forecast, irrespective of its quality.

8. In Chapter 4 we collect together our conclusions and recommendations. As indicated earlier we consider the exercise as only the start of a process requiring much more detailed analysis leading to implementation and resource allocating decisions. Our principal recommendation therefore is that "a process should be established for identifying exploitable areas of science, which has some certainty of continuity, for the long-term economic health of the country."

11. In arriving at these conclusions we carried out a review of the current state of areas of science in the UK and their relationship with market need and technological opportunities. We looked at science from a traditional disciplinary focus and also across traditional boundaries. These preliminary findings are not published in this report but have had considerable influence on the conclusions we reach.

CHAPTER 1. INTRODUCTION - ALLOCATING RESOURCES TO SCIENCE - THE NATURE OF THE PROBLEM

1.1. Background and Remit

1.1.1. Central to the ACARD terms of reference is a charge "to advise the Government and publish reports as necessary" on " the application of research and technology, developed in the United Kingdom and elsewhere, for the benefit of both the public and private sectors in accordance with national economic needs". The Council has published several reports on subjects relevant to this remit, for example, robotics, computer-aided techniques, advanced manufacturing methods. The object of those reports was to focus attention on new technologies in order to encourage their exploitation by industry.

1.1.2. A number of steps back from the point of exploitation of technology is a stage of scientific experimentation which increasingly forms the base from which new technologies and innovation flow; however, not all basic scientific research is exploited or exploitable. Historically, a prime motive of the scientific process has been the advancement of knowledge, but rarely does scientific progress occur without a point or points of reference; cross-fertilisation of ideas has been a rich source of scientific innovation in the past. Major scientific discovery is usually made in fields which have already been identified as having significant potential. In the fullness of time, many such discoveries lead on to new technologies. Such notions prompted the Council to consider the feasibility of identifying the fields of science on which future technology and innovation might be based. If such a process were feasible there would clearly be implications for technological development, industrial competitiveness and for resulting economic considerations. ACARD decided, therefore, with the endorsement of the Advisory Board for the Research Councils, to examine the feasibility of identifying areas of science which had significant economic potential for the future. At the same time, it was thought desirable to examine the adequacy of the national scientific research effort in relation to such scientific fields which were identified.

1.1.3. We were invited by ACARD, therefore, to form a Study Group with the following terms of reference -

a. to report on those areas of science and specific scientific developments likely to have significant economic consequences within ten years and within twenty years;

b. to comment, as far as possible, on the adequacy of the above areas of science in the UK in terms of the technology perceived to be required in the future.

1.2. Scope of the Study

1.2.1. In the spectrum of basic and applied science, there will be areas that informed observers will select as more likely than others to have economic potential on a ten or twenty year timescale. The exploitation of these areas may result in changes in industrial practice, the service sector, national infrastructure, health care, social conditions, the environment, lifestyles, educational techniques, etc. Perceptions of the areas which have economic potential will be formed from two fundamental considerations:

a. judgements on fields of scientific research which are likely to lead to new industrial and commercial opportunities;

b. judgements on the changes in society and the marketplace which are likely to require the application of new technology.

1.2.2. Science comes in an infinite variety of shapes and sizes. The private sector often has a clear idea of where it thinks the research which it undertakes is leading in terms of the marketplace. However, some private sector research and much public sector research is of a more speculative or curiosity-driven nature. The initial reasons for such research may be for advancement of knowledge but ultimately important technologies may arise. Development and commercial exploitation of such technologies will depend on a complex of factors but finally a market must have developed. Predictions about the potential of curiosity-driven activities implies some arbitrariness, but informed judgement at the time may in many cases have yielded a reasonable assessment of the likely potential of such research. <u>We considered the feasibility of such a process to be central to our remit.</u>

1.2.3. The scope of the study was confined therefore to those areas of science which we considered likely to be economically significant in the future, and included all the major fields, such as health, communications, energy, space, manufacture, defence, etc in which such areas might be located.

1.2.4 It is neither likely nor desirable that the <u>entire</u> budget for UK science should be treated in strategic terms. Many fundamental areas of research will remain, where the long-term interests of the UK are best served by leaving first-rate scientists to judge fruitful areas of research quite independently from external pressures. There are motivations for practising science other than the purely economic ones, e.g. for intellectual curiosity and for education and training. However, economic reasons cannot be ignored in the formulation of British science policy. It is a question of balance, and it is our judgement that economic and social factors have been given less weight in the formulation of science policy than is justified by Britain's economic circumstances.

1.3. <u>Annual Review of Government-funded R & D</u>

1.3.1. In June 1982, the House of Lords Select Committee on Science and Technology in its First Report made a number of recommendations about the organisation of Government advice on science. A major feature of the reply (Cmnd 8591) by Government to the report was the decision to introduce a system of Annual Reviews of Research. ACARD was invited by Government to comment on the issues raised in the Annual Review in order that independent advice could be obtained on the allocation of public expenditure resources to R & D.

1.3.2. The first review carried out in 1983 concentrated on assembling a database of Government R & D expenditures, and on establishing procedures for the collection of such information regularly in the future. It was not intended in the 1983 Review to set Government-funded R & D in any national or international framework. This was a major aim of the subsequent review which has recently been published. The 1984 review emphasised that decisions on levels of R & D funding must be a matter of informed judgement based on knowledge of the prospective subject of study, taking into account other expenditure priorities. ACARD has provided its advice to Government on both reviews as an input to the process of such informed decision-making. The 1984 Review also commented that the analysis was a broad-brush exercise which could not fulfil all the objectives set out in Cmnd 8591 for the Review. It could only indicate areas where expenditures appeared to be out of line, whether with international figures or by comparison with their expected economic significance: further studies would be required. We see the study which we were invited to undertake very much in this context.

1.3.3. Cmnd 8591, in commenting on the Annual Review, concluded that "the analysis required will not be a facile choice of areas where more money should be spent. In the Government's view, overall UK expenditure on research and development as a percentage of GDP is sufficient. Skillful value judgements as to allocation of financial and manpower resources are, however, needed. This will involve distinguishing between vital and dormant areas, identifying gaps, disparities and duplications, and considering the opportunity cost of relinquishing certain areas of research. The emphasis will be on review of long-term plans". Clearly the study which we were asked to undertake by ACARD is highly relevant to the objectives outlined in Cmnd 8591. As indicated above, the Annual Review is well-established in terms of the basic information which it provides on allocations of Government R & D funding, and attention should now be focussed on scientific aspects of priorities for Government R & D funding.

1.4. National Scientific Priorities

1.4.1. The UK carries out roughly 5% of total world R & D, and clearly is not involved in many areas of research which are covered by other countries. Therefore in the current range of national R & D activities a process of selection has taken place, however carried out, in order to determine which areas should be supported to the exclusion of others. It is the process of selection and results of the process which is relevant to the second part of our terms of reference.

1.4.2. Concern has been expressed in recent years by those with interests in science policy that the processes by which national scientific priorities were determined were not clearly visible. There was no mechanism by which to assess the national competence in any particular technology or branch of science or to judge whether the process of selection paid sufficient regard to national needs in relation to factors other than those concerned mainly with excellence in scientific research. A natural linkage between the basic research funded by Research Councils and applied research carried out by other bodies is not apparent.

1.4.3. At a national level, a need for clearer identification of priorities relevant to fundamental, strategic, and applied research has been expressed. It was concluded at a seminar in 1982 organised jointly by the Leverhulme Trust and the Society for Research into Higher Education that "A national research policy is required to guide the allocation of public money to fundamental and strategic research". The report of the seminar went on to suggest that priorities could not be left entirely to government, and that "there is a need in this country to find a mechanism which will allow the greater involvement in the determination of research priorities of higher education institutions, the UGC, the Research Councils, the scientific community and likely users of research - industry and government".

1.5. International Aspects

1.5.1. The nature of international competition and the cost of research are such that the development of new technology cannot realistically be treated in the context of a closed economy. Trade, foreign investment and licensing are alternative ways in which the returns to research may be garnered. Science in a historical context has rarely been hindered by international boundaries, and the scientific process has been benefitted from the close interaction of scientists in the world community.

1.5.2. To maintain its position within the world economy the UK will be required to draw deeply on its own resources of inventiveness and innovation. A thrusting higher educational research system is needed responsive to the demands to which it will be subjected. Countries which appear to have enjoyed success in scientific research and its application in recent years have made conscious efforts to formulate national research priorities for the basic sciences. The Japanese with their long-term plans and French with national symposia on science seem to have developed processes for identifying the scientific priorities, for influencing government to make funds available for such priorities, and for obtaining a commitment to implementation of the priorities.

1.6. Outline of the Report

1.6.1. We noted at the outset of this exercise that those countries which had enjoyed most success in recent years in their exploitation of science had tended to adopt an approach or process for guiding national scientific and technological activities which was closely related to the ways in which the economy and society of the country were developing. In this report, therefore, we discuss the relationship between such activities and support in strategic science and generic technology and industrial and commercial markets. This discussion is contained in Chapter 2. Ways in which different countries go about the process of relating scientific priorities to economic and societal factors were investigated by commissioning a study with consultants. The results of this study and the approach which we subsequently decided to adopt are outlined in Chapter 3. In Chapter 4 we conclude by giving our considerations and recommendations on a process for relating national priorities in strategic science to the needs of the economy and society.

CHAPTER 2 - SCIENCE, TECHNOLOGY AND ECONOMIC PERFORMANCE IN THE UK

2.1.1 Our terms of reference in this exploratory study are to identify exploitable areas of scientific research, i.e. areas where there is anticipated to be a basis for profitable commercialization over a period of ten to twenty years. In this context, commercialization means transformation of scientific understanding into profitable new products and processes by UK firms. The purpose of this chapter is to provide a brief overview of the main issues which arise in the process of assigning promise to areas of science. We do not attempt to hide the complexity of the questions we discuss. Nor do we pretend to forecast future states of the world with any precision.

2.1.2. In 1969, the Department of Education and Science published a report by the now defunct Council for Scientific Policy (CSP) entitled "An Attempt to Quantify the Economic Benefits of Scientific Research". The report pointed to the close association between applied research and its economic justification, and suggested that although fundamental scientific research was carried out for its cultural value and for the intellectual challenge, such research had often unexpectedly also given rise to major technological progress. Suggestions were made on how the economic benefits of science might be assessed, and on the need to make an appraisal of underlying scientific discoveries in relation to their economic significance for the industries on which they were based. The aim of such assessments was to make possible in time the prediction of long term economic changes resulting from support of particular scientific areas.

2.1.3. At the time, the report was particularly forward-looking. Thus although the CSP Report objective of a series of <u>ex post</u> studies of science based industries was somewhat narrow, in that it was confined to the associated underlying science, the report also recognised that it might be necessary eventually to consider the interrelations between all science-based industries and all associated scientific discoveries. It was realised that such a task would not be straightforward, even with the assistance of techniques such as systems analysis and critical path analysis. Furthermore the report also acknowledged, more in passing, that in such ex post rationalisations, it might be difficult to distinguish features of society resulting from previous scientific activity from changes due to other organisational/market forces in society, or to determine the extent to which such changes were related to previous technical/scientific advances. Nevertheless, it was considered, in full recognition of the magnitude of the problem, that it would be worthwhile to explore these ideas further, and the CSP set up a Working Group to consider possible methods of quantifying the economic benefits of scientific research. Before the Working Party had reported, however, the Council was disbanded in 1972.

2.1.4. Since that time interest in such studies and assessments have been pursued in other fora both nationally and internationally. Both academia and industry have sought to develop and analyse information on scientific and technological activities and relate these to technical innovation and development in order to improve the basis for policy and theory. In such analyses there is a clear difference in approach to the science carried out in the private sector to that carried out in the public sector. Although scientific assessments in both sectors rely to some extent on extrapolations of past trends, assessment of technological potentials of applied research by industry rely on a more structured approach, incorporating economic, technological, socio-political and other parameters, than does assessment of public sector science. Assessment of public sector research is inherently more difficult than that of private sector research because the objectives are less clearly defined in the economic sense and it is less process or product-orientated. Most countries can no longer afford to leave scientific progress to chance, and are developing techniques for monitoring the nature and direction of scientific advances to aid and improve the planning of research. The study of the social organisation of research areas and specialities has, over the last decade, become an important field of research within the sociology of science.

2.2 Scientific Support and UK Economic Performance

2.2.1 The resources available for scientific research depend primarily upon the level of gross domestic product, and any substantial increase in resources for science is most likely in the longer-run to be funded by economic growth. The economic performance of the UK economy since 1945 has been sufficiently weak compared to that of other OECD countries to raise doubts about the capacity of the UK to support the scientific community at previous levels. The support per scientist has, in the past, been greater than in most European countries and falls little behind that in the USA. It is likely to become lower compared with both in the future, which will be of importance because of the competitive nature of science. The relatively poor performance of the UK economy is reflected not only in the statistics of per capita income growth but also in the statistics of foreign trade, with the UK share of world exports of manufactures falling from 20% in 1954 to less than 9% in 1984. In world terms the UK is a small economy with its standard of living heavily dependent upon foreign trade. The trade pattern is no longer one of exporting manufactures to less developed and Commonwealth countries in exchange for imports of food and raw materials. Rather it is dominated by trade in manufactures and semi-manufactures with the advanced industrial countries of Western Europe, North America and Japan. In 1984, over 75% of UK imports and 66% of UK exports involve trade in highly competitive markets for manufactured and semi-manufactured goods compared with figures of 53% and 79% in 1955. So far as services such as banking, insurance, consultancies, etc are concerned, the export ratio was 23.5% in 1983 comparied with 27% in 1962 and the import ratio 18.5% against 23% in 1962.

2.2.2 The exploitation of North Sea oil resources has had a profound effect on the UK economic structure. The higher real exchange rate which has resulted is an important factor in `crowding out' UK manufactured exports and generating in 1983 a negative trade balance on manufactured goods for the first time since records began. Yet North Sea oil must give out some time, be it in 20, 50, or 100 years, and the reduction in income will require the development of new export opportunities if UK standards of living are to be maintained, let alone grow at average European rates.

2.2.3 It is here that a policy for strategic science becomes particularly significant. The export opportunities which maintain standards of living are those which offer high value added per unit of employment; products with a knowledge base in advanced technology which can be sold on world markets at favourable terms of trade. The products of relatively mature technologies are increasingly the comparative preserve of low-wage newly industrializing countries with which the UK has little realistic prospect of competing without a drastic fall in living standards.

2.2.4 Japan, for example, has experienced very rapid import penetration from less developed countries in a number of mature technological areas, and has yet maintained the most impressive growth rate in the industrial world. The reason lies in the close link between structural changes and economic progress as new dynamic industries expand and displace existing activities. In the general process of growth the agricultural sector declines relative to manufacturing, which in turn is eclipsed by the growth of the service sector, while within the manufacturing and service sectors new activities continually emerge to compete with and displace established activities. No single technology offers unlimited scope for improvement so the process of growth has to be sustained by new economic impulses based upon innovation, that is, upon an entrepreneurial injection of new technological activities into the economy.

2.2.5 The role of strategic science policy over the next twenty years of UK economic growth then becomes clear. On the one hand, it should contribute to existing activities keeping close to world best practice. On the other hand, it should respond to the important export and growth opportunities which lie in newly emerging technologies where the knowledge base is changing rapidly enough to prevent low-wage countries establishing a technological presence. To grasp opportunities at the cutting edge of international competition will require new patterns of resource allocation, and the allocation of resources to strategic science should be seen as an integral part of this market driven process. Structural change is, of course, painful in the short-term as particular skills are no longer needed and regional concentrations of industry decline. But, over the longer-term, a failure to develop new economic activities has even more painful consequences for the nation as a whole. Of itself, strategic support of science is a small but necessary part of this picture of growth and transformation.

2.3 The Nature of Exploitable Science

2.3.1 An exploitable area of science is one in which the body of scientific understanding supports a generic (or enabling) area of technological knowledge; a body of knowledge from which many specific products and processes may emerge in the future. It is this connection with future technological development which gives the exploitable area strategic importance. Thus exploitable areas of science exist "where the basic principles are known but the final products have yet to be identified" [Improving Research Links between Higher Education and Industry, ACARD/ABRC, 1983, p.11]. It is intrinsic to this definition that exploitability depends upon three sets of considerations:

i. The potential for development within the area of science;

ii. The generic technologies which will be advanced by a greater understanding of the particular fundamental scientific principles; and

iii. The potential areas of application which products and processes flowing from the generic technology will have.

2.3.2 According to Frascati definitions of R&D, basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application in view. So far as the Annual Review of Government-funded R&D is concerned, it was recognised that basic research was often considered by the funding agency to have a strategic dimension, and that the division between basic and strategic aspects of such research was difficult to identify. For applied R&D, it was possible for the customer to distinguish and quantify the precise practical aims and objectives of the programmes. Applied research with strategic aims was, therefore, research directed primarily towards practical aims or objectives, but it was too early in the evolutionary cycle of the subject under investigation for the eventual applications to have been clearly specified. The actual duration of the strategic phase of the evolution of a field of study would vary widely from field to field.

2.3.3 The identification of promise will require a blend of judgements involving questions both internal to and external to the pursuit of fundamental science. The matching of extrinsic and intrinsic criteria in the pursuit of national objectives will, in turn, require an institutional and decision-making structure which does not locate strategic science and industry in different, mutually exclusive categories. Rather it will require a framework which draws together the relevant knowledge inputs, establishes communication between science and industry, mobilizes resources in pursuit of the strategic objectives, and changes the balance of support as the potentials of market exploitation, scientific advance and technological development evolve. Flexibility in response to changing priorities will be a quite central element in any policy of strategic support for science. Government programmes with emphasis on pre-competitive research involving collaboration between university departments and industry is one institutional structure which may find wider application in a policy of strategic support.

2.3.4 It will be clear that technological knowledge bridges the gap between strategic science and the market place. The likely success of a programme of strategic scientific support will depend on not treating the development of the scientific and technological knowledge as independent, sequential stages but rather in treating them as interdependent processes, advancing in step in the development of a generic pool of technological knowledge. To seek to organise science in such a way that it leads naturally to exploited technology is the objective. Strategic science is a national investment to be justified in terms of the national return it promises to generate. Therefore the organisation of strategic science should reflect this need for results to be followed by exploitation in the national interest. Effective interaction between industry and the scientific community is vital if strategic research is to succeed.

2.3.5 It would be foolhardy in the extreme to pretend that the identification of promising areas and their commercialization is straightforward. Picking the precise winners is not a feasible policy option. The process by which new industrial activity is generated and absorbed into the prevailing economic structure is one of immense complexity. Nonetheless it is clear that technological innovation has been and will continue to be the mainspring of economic growth and, moreover, that future technological development will depend closely upon advances in scientific understanding.

2.3.6 To forecast exploitable areas in any precise way is not possible, the links in the chain are many, the uncertainties at each stage considerable, while the possibilities of success or failure also depend upon decisions made in the many countries which compete with the UK in world markets. Nonetheless, it is we believe possible to identify broad areas of activity where a change in scientific knowledge or of market trends will make it profitable for industry to develop new products and processes.

2.3.7 Rather than pick winners in this narrow sense, strategic policy is concerned to create a reservoir of knowledge out of which the, as yet unidentified, winning products and processes will emerge.

2.3.8 The case for public support of strategic science lies in its having long-term implications without as yet offering a return to immediate exploitation in the market place. Thus strategic science falls in the gap between fundamental science and applied science, being neither the primary concern of the university sector nor of private industry. The time horizons, attitudes to risk, and objectives which motivate scientific research in the two sectors are sufficiently different to provide little incentive for strategic research to be performed by either. Like basic research, strategic research is concerned with advancing fundamental knowledge, and like applied research it is concerned with developing new technological possibilities. It is at this interface when different attitudes to risk and different objectives meet, that the problems of identifying and funding strategic research arise.

2.4 Selectivity and Strategic Support

2.4.1 The resources available for scientific research are always limited relative to the claims which can be made on them. Science policy inherently involves questions of choice, the setting of priorities, the sacrificing of some areas of science in favour of others. Naturally this entails risks but this is true for any realistic situation in which limited resources have to be allocated.

2.4.2 Within this context a policy for selecting exploitable areas of science explicitly introduces criteria for choice which are external to science. Within the current Research Council system the allocation of funds to science proceeds via a complex system of peer review, based primarily on criteria of intrinsic scientific worth and the capability of the competing research groups. Questions of industrial relevance are not ignored but no formal mechanism exists either for gathering information in the detail required or for systematically evaluating and presenting this information within the review process. Perhaps the one exception occurred when SERC successfully transferred sizeable resources to their Engineering Board on which industry has a major voice. Nor is there a system to determine such relevance of commissioned research which is wholly aimed to produce benefits as perceived by Government departments.

2.4.3 In allocating funds for strategic reasons internal scientific judgements remain indispensable but are no longer sufficient, and have to be supplemented by judgements of commercial and technological relevance, that is, by judgements of the external worth of the particular scientific area. In general terms these external judgements relate to two situations:

i. Where the products and process which ultimately stem from the strategic science are valued in the market place.

ii. Where a need is apparent but the commerical criteria are not applicable, either because relevant markets are nonexistent, or give distorted signals to decision-makers. The science and technology related to environmental protection, health and defence are important examples within this category.

2.4.4 The definition of the margin between strategic and non-strategic work will be an important element in a policy to support exploitable areas of science. Considerations of strategic research cannot avoid treatment of fundamental research as well, since the use of external criteria implies comparisons of the competing demands of strategic and fundamental research for the same resource.

2.5 Investment Decisions and Strategic Science

2.5.1 The support of exploitable areas of science can properly be viewed as an investment decision, in which current outlays are incurred in anticipation of future returns. The objective would be to create a portfolio of areas of strategic science on which UK industry would draw over an extended period, to ensure its future competitiveness in international markets as outlined in the joint ACARD/ABRC report published in 1983 on improving research links between higher education and industry.

2.5.2 The elements of a strategy are criteria for choice, the identification and collection of relevant information, and an institutional mechanism which ensures that UK industry does indeed draw successfully on the strategic sciences and related enabling technologies. A policy which succeeds in generating good, commercially relevant knowledge will have failed if UK firms do not exploit the related technological opportunities. It will have failed *a fortiori* if that knowledge base is exploited by foreign firms. The matching of knowledge and exploitation in the UK is the key objective in any policy of strategic science. A successful strategy will require that a process is established with clear elements of continuity to achieve this objective.

2.5.3 The choices to be made in allocating funds to strategic research fall into two related categories: the areas of science to be given strategic status; and, the levels at which the selected are to be funded. If one area is selected as exploitable, the level of support should reflect the date in the future at which profitable commercialization of the related technologies is expected. The funding policy should provide the resources to ensure that all relevant knowledge is acquired by the expected date of commercialization. That the timing element is important in strategic research is not surprising. Modern industrial history is replete with examples of misplaced technological endeavour in which either the UK was too late - allowing competitors to build a commanding commercial advantage - or too early - investing in a technology before market support had emerged. The greatest increase in national wealth is obtained not simply by developing new technologies but by developing them at the right time. The ability of UK firms to exploit promising science is not independent of the strategy of foreign competitors or their effectiveness in development and exploitation. Of course, the fact that any area of science is not of strategic importance at the present moment in no way rules out its becoming strategic at a future date. Successful policy will have to accommodate shifts in priorities over time and be flexible enough to effect these changes.

2.5.4 Strategic support should reflect this by giving greater emphasis to areas with more immediate prospect of economic return and less weight to areas whose exploitability is expected in the more distant future all other things being equal.

2.5.5 The usefulness of any investment framework lies in the insights which arise from its systematic application. By providing a framework for informed choice, it identifies the information which is required, even if in practice that information can be based on no more than intelligent guesswork.

2.5.6 Broadly speaking, the framework identifies costs and benefits associated with the support of strategic research. The relevant costs relate to the programme of research funding over a period of years, while the benefits relate to the commercial and other consequences of exploitation <u>net</u> of the costs of translating the generic pool of knowledge into specific products and processes.

Whereas the support of exploitable areas of research will be met by public funding, the costs of developing specific products and processes will fall to a greater degree upon UK industry. The balance of funding between public and private support will require careful consideration to ensure that promise in science is translated into exploitation in the market place.

2.6 The Costs of Strategic Research

2.6.1 The costs of strategic research depend on the capital intensity of the research process, the quality of the research teams, and the level of fundamental understanding which exists in the research area. Since the outcome of a research programme is surrounded by uncertainty, some judgement has to be made as to the bounds of possibility, and the `costs' adjusted accordingly. Also, it is more difficult in some areas than in others to change course in response to new opportunities because of long lead times in equipment and skills, and this is often an important factor in making choices.

2.6.2 All other considerations being equal, the case for giving an area strategic support becomes stronger the lower is the anticipated cost of acquiring the relevant knowledge.

2.6.3 The nature of international competition and the cost of research are such that the development of new technology cannot realistically be treated in the context of a closed economy. Trade, foreign investment and licensing are alternative ways in which the returns to research may be garnered. Science in a historical context has rarely been hindered by international boundaries, and the scientific process has benefitted from the close interaction of scientists in the world community. Indeed, the fact that the results of scientific research are disseminated internationally implies that the UK can supplement its own strategic programmes by drawing upon the results of foreign research. It is frequently observed that foreign technological programmes successfully exploit the results of UK research and there is no _a priori_ reason why the converse should not hold.

2.6.4 It is unlikely, however, that this will be possible unless the UK maintains at least a gatekeeper presence in a given area, with a sufficient investment in manpower and facilities to replicate and improve on foreign advances as and when they occur. Below this threshold, which will vary across sub-disciplines of science, the UK could not hope to gain direct access to the best practice strategic science developed overseas.

2.6.5 International collaboration may also be possible in some circumstances, provided that the countries can agree on strategic objectives. The extent to which UK strategic science can be based upon international collaboration will depend on the extent to which exploitable areas have been identified world-wide, and the extent to which UK policy seeks to develop areas independently from major competitors. Joint ventures between UK companies and between UK and foreign companies may also offer advantages in the development of specific products and processes arising from the generic pool of knowledge. This may be particularly relevant where UK companies are small relative to Japanese, American and European competitors.

2.6.6 To maintain its position within the world economy the UK will be required to draw deeply on its own resources of inventiveness and innovation. A thrusting higher educational research system is needed responsive to the demands to which it will be subjected. Countries which appear to have enjoyed success in scientific research and its application in recent years have made conscious efforts to formulate national research priorities for the basic sciences. The Japanese with their long-term plans and French with national symposia on science seem to have developed processes for identifying the scientific priorities, and for obtaining a commitment to implementation of the priorities.

2.7 Benefits from Strategic Science

2.7.1 The benefits flowing from the programme of strategic science depend ultimately upon the products and processes which UK industry develops and exploits in world markets. Elements of entrepreneurship are an indispensable component of a successful strategic policy. The benefits will in each case depend on the improvement in performance that the new products and processes offer to their users, either in terms of cost reduction or enhanced capabilities. The greater the advantages which the new technologies provide, the greater will be their ultimate application, and the more quickly they will be absorbed into the economic structure. The pace of absorption is of considerable importance in determining the economic return to innovation. The application of new technology always involves the displacement of existing productive activities and there are natural barriers to this substitution process, partly economic and partly relating to the inherent uncertainty surrounding the characteristics of new technology. The more quickly markets absorb the new technology, the greater the wealth generated, and the greater the justification for supporting the underpinning areas of strategic science. One need only to note the power of compound interest to see the importance of timing. At a rate of interest of 10% (a modest one for risk-laden ventures) a sum of £1,000 today would have an equivalent present value of £390 in ten years time and only £150 in twenty years time. All other things being equal, the case for strategic support is greater the greater the range of application of the new technology and the quicker the economic application is likely to occur.

2.8 Niche Concept

2.8.1 An ecological analogy is sometimes helpful. When treating the question of competition between different species, ecologists employ the concept of a niche to reflect the interaction between environment and the rival species. Exploitable areas are akin to new species introduced into a commercial habitat, populated with existing industrial activities, and the problem is to identify the niche and the costs of filling it with profitable UK-based activity.

2.8.2 Consider, for example, developments in opto-electronics. The technology flowing from this could affect a wide variety of information-disseminating activities. The opto-electonics niche could be identified with regard to:

a. A range of existing information-disseminating activities which could be directly affected. Telephone, telex, newspaper, and library activities come immediately to mind, as do cable television and possible niches in medical electronics and control engineering.

b. Alternative technologies which compete for a niche, eg cable versus satellite based communications.

2.8.3 The extent to which the potential market benefits are captured by foreign firms must also be part of the assessment procedure. From a narrow viewpoint the UK, qua consumer, can always obtain the benefits of new technology by importing the relevant products. However, in so doing, it forfeits the incomes which could be earned in their production and thus limits the general capacity to consume and benefit from the new technology. Considerations of international competition impinge upon the selection of exploitable areas in a number of ways. The ability of UK firms to exploit overseas markets enhances the return to UK strategic science. Evidence of foreign strategic programmes provides a case for accelerating UK efforts, in order to prevent competitors developing a lead time which renders unprofitable UK production. Conversely, in areas where UK industry does not have an anticipated competitive edge, the case for a strategic research underpinning of these technologies is correspondingly reduced.

2.9 Net Benefits

2.9.1 In assessing the benefits expected from a programme of strategic science, account must be taken of the very high development costs likely to be incurred in translating the pool of generic knowledge into specific products and processes. Such costs must be subtracted from the identified commercial returns to arrive at a net benefit figure. These downstream activities have rightly been identified as major overhead costs - incurred in development, design, construction of pilot plant, and other activities to capitalize on generic knowledge. To spread these overheads requires a large market, and for the UK this can often be achieved only in international terms, by capturing markets within the advanced OECD countries of Europe and North America.

2.9.2 To minimise the costs of exploiting the generic pool of knowledge it will be necessary to ensure close collaboration between industry and the scientific community: to ensure that research objectives and resource commitments illuminate the problems found in particular areas of technological development. The Alvey programme may provide a good guide in this respect.

2.10 Identifying Exploitability: Aide-Memoire

2.10.1 The issues raised so far may be summarised in terms of a sequence of questions, each one focussing upon a particular aspect of exploitable science.

i. Which areas of generic technology are supported by a particular area of strategic science?

ii. Has the UK the scientific resources to advance a particular area of strategic research? If not, how quickly can resources be acquired, eg by changing the emphasis of undergraduate and graduate programmes?

iii. Within a generic technology what classes of new products and processes will become possible within a twenty year horizon?

iv. What indicators are there of the likely costs of translating knowledge from the generic pool into marketable products and processes?

v. In which areas of existing industrial and commercial activity will the new products and processes find initial application? What advantages will they offer and how might markets respond to these advantages?

vi. How quickly might the perceived markets develop and what might be the ultimate market niches of the new products and processes?

vii. What evidence is there of a foreign industrial presence in the relevant areas and what implications does this have for UK market share?

2.10.2 It is inevitable that hindsight will indicate opportunities missed and promise extinguished but such risks are inherent in any process of resource allocation in which relevant information is scarce. They should, however, be minimized by adopting rules of thumb of the following simple kind:

i. Support a portfolio of strategic areas with individual prospects for exploitation which are positively correlated or at worst independent;

ii. Select strategic areas where the generic technologies suggest a wide field of industrial and commercial application;

iii. Continuously monitor science and technology programmes in major international competitors;

iv. Establish close liaison between the scientific, industrial and financial communities in the UK to facilitate the free flow of information on exploitable science and the establishment of a consensus view;

v. Terminate programmes where the case for them is no longer supported by criteria of strategic promise.

2.10.3 Precise answers to these questions will never be available for today's decision-makers, they will only be revealed as the new products and processes are absorbed into the economic structure. However, intelligent guesses can be made and these should provide an initial guide to areas of strategic importance. Strategic decisions should not be seen as irrevocable. A policy for strategic science is a process, in which decisions are made in the light of the best available information and reviewed as and when new information becomes available.

Table 1

Product Structure of World Exports (%)

Produce	Total		OECD		Developing Countries	
	1960	1979	1960	1979	1960	1979
Food	17.5	10.6	13.9	10.2	29.5	12.4
Raw Materials	16.7	7.4	13.2	6.9	27.9	8.5
Fuels	9.9	20.3	4.0	5.9	28.0	56.6
Chemicals	5.8	7.2	7.6	10.4	1.1	1.6
Machines	24.5	26.9	28.0	35.2	0.7	5.2
Textiles	4.9	3.0	5.6	3.3	3.3	2.6
Clothing	-	2.1	-	1.7	-	3
Vehicles	3.2	3.7	4.5	5.4	-	0.2
Other Industrial	27.1	25.2	31.8	29.6	12.3	15.2
Metallurgical	9.0	4.3	10.2	5.6	5.2	1.0

Source: UN Monthly Bulletin of Statistics

Table 2

Percentage Share of Developing Countries in Selected Imports of Advanced Industrial Countries

	USA		UK		Japan		West Germany	
	1965	1979	1965	1979	1965	1979	1965	1979
Textiles	37.7.	48.5	33.3	18.4	9.1	66.9	8.8	19.3
Iron and Steel	2.7	15.1	2.3	5.3	18.8	66.7	1.3	3.6
Clothing	35.4	85.9	48.5	52.8	21.3	74.7	20.0	36.9
Electrical Machines	7.1	47.0	5.2	11.0	0.6	27.6	1.2	10.7
Detergents/ Cosmetics	30.4	26.2	13.9	13.1	13.3	7.1	3.5	2.5

Source: OECD Foreign Trade Statistics

[include figures on imports as a percentage of total consumption]

Table 3

Economic Structure of Selected Countries (% GDP)

	Agriculture		Industry		Services	
	1960	1980	1960	1980	1960	1980
USA	4	3	34	30	62	67
UK	4	2	37	29	59	69
West Germany	6	2	47	40	47	58
Japan	13	5	37	32	50	63
Spain	22	7	29	27	49	66
Brazil	18	9	19	31	63	60
India	47	31	15	19	38	50
South Korea	37	16	17	32	46	52

Source: UN Statistical Yearbook

CHAPTER 3 - APPROACHES TO FORESIGHT ACTIVITY IN STRATEGIC SCIENCE

3.1.1 We discuss briefly in this chapter some current approaches to assessing the potential for emerging areas of science in both the public and private sectors. Also described is a survey which we commissioned with the Science Policy Research Unit, Sussex University, to investigate how some other major industrialised countries went about the process of generating a view on scientific priorities. Finally we outline our approach to developing an overview of exploitable science.

3.2. Technological Foresight in Industry

3.2.1 Technological forecasting is an aspect of long term market forecasting, which became of widespread interest to many major companies in the mid-1970s. Various techniques were developed each somewhat similar to the other, with the basic objective of assisting in the decision-making process on R & D and innovation. A typical approach was to assemble a high level corporate team or engage a firm of consultants to examine future technological trends and the related market potentials, the reasons for such trends, the way in which they might impact on company business, and how the company should respond to the opportunities presented. For many companies the results of such types of forecasting proved to be disappointing, perhaps because many forecasts were merely extrapolations at a time of high economic growth and they identified little that was not already known, whereas the economic changes in the last decade have produced many discontinuties which had not been foreseen. The lessons from such exercises indicated that forecasting was more successful when

a. the innovation process was clearly understood ie technology `push' and market `pull' were both essential in company research and innovation;

b. close collaboration was required between those undertaking the forecast whether inside or outside the company and research workers and management within the company;

c. a receptive attitude to the forecast was required at senior management level in the company.

Forecasts also tended to be more satisfactory in relation to a narrow range of technology than when consideration of a broad range of technologies was required.

3.2.2. In reaction to the relative lack of success, the credibility in the techniques used has been reduced; nevertheless, organisations require a view of the future in order to develop strategies which enable them to adopt rapidly in a period of fast-moving economic and scientific changes. Such a view can only be obtained by using the most reliable sources of data and developing insights in a systematic and structured fashion. The technologist involved in innovative development often underestimates the effort required to complete development of the innovation, and often has inadequate perception of changes in market or technological conditions which might affect exploitation of the innovation. The success of innovation is dependent on the relationship between technological potential, and future market need. Completely accurate forecasting is not possible, but such precision is not essential anyway for many long-term planning purposes. The error in forecasting should not be a major determinant of the success or failure of an innovation. But forecasting can be a valuable tool to assist in decisions to identify innovations likely to be a major success and to avoid major failures. Perhaps the greatest value in such forecasting activities is the development of comprehensive databases and the increase in confidence which their use in planning future directions. Such decisions are concerned essentially with human behaviour and as we discuss later in relation to technological assessment in Japan, forecasting is closely related to the behavioural aspects of decision-taking.

3.3. Scientific Foresignt in Publicly Funded R & D

3.3.1. Technological forecasting holds greater potential, in spite of the aforementioned difficulties, for strategic or applied research than for basic or curiosity-orientated research. But the increasing complexity of organisation and management of publicly funded R & D, against a background of rapid economic and scientific change, has highlighted the need to develop procedures not only for recognising the important areas of curiosity-orientated science <u>per se</u> but also for identifying the areas of such research with significant strategic potential, in order to establish priorities for support of these areas.

3.3.2. The apparent absence of an underlying rationale for support of basic science was noted some 20 years ago. Two sets of criteria were suggested for determining the relative assessment of support for different scientific activities. The first related to internal criteria relevant to the advancement of scientific knowledge and the second, to external criteria, related the wider effects which science might have on other scientific fields and to society, for example, in the form of new ideas and techniques for industrial exploitation. In general, internal regulation has been the primary mechanism by which basic science has been organised and the distribution of resources within fields and specialities controlled. The system used for such regulation has generally been termed peer-review. Up to the mid-1970's when support for scientific research was increasing rapidly, such a system worked reasonably efficiently in ensuring that most science of merit was supported. However, the slow-down in growth of science budgets has placed pressures on the system, and attention has been drawn by Irvine and Martin to three problems to which such pressures have produced

a. the resources which big sciences consume is disproportionate to the total scientific activity which it generates;

b. the concentration of research activity within fewer institutions which has tended to reduce their accessibility to the wider scientific community;

c. the peer review system had become less appropriate as a mechanism for restructuring scientific activity.

Another problem relates to the unsatisfactory nature of peer-evaluation in identifying declining science areas and groups, because of the deep-rooted institutional and social factors which would require to be addressed.

3.3.3. Although external criteria have played a part in determining the overall levels of support for science and to some extent its distribution, such criteria have tended to reflect the needs of the scientific community along the lines described above. However, recent resource constraints have increased the pressure on the scientific community to have greater regard to external criteria in order that basic research results in more tangible and practical benefits for society. Of particular concern is the need to establish procedures for determining priorities between fields. The present distribution possibly reflects more post-war scientific planning decisions than a conscious effort in subsequent years to establish priorities on a systematic basis defined by present or future national needs. The availability of improved statistics through, for example, the Annual Review of Government-funded R & D, and work of bodies such as the Advisory Board for the Research Councils, University Grants Committee, National Advisory Board, etc will assist in providing a clearer picture of R & D support and facilitate a more directed approach to the organisation and management of publicly-funded R & D.

3.4 Other Foresight Activities

3.4.1 Science and Engineering Research Council

3.4.2 In September 1984, the Science and Engineering Research Council (SERC), published a report entitled "A Strategy for the Support of Core Science" which represented the SERC Science Board strategy for defining and developing the research themes crucial in underpinning the science-base sectors of the national economy and for which a strong core science capability was required. In developing their strategy, the Board emphasised the importance of multidisciplinary activities and proposed that SERC central facilities could perform an important function in promoting multi-disciplinary studies. Difficulties imposed by the compartmentalised funding of research were recognised.

3.4.3 We applaud this initiative by the Council particularly the recognition that a continually evolving strategy is required incorporating not only considerations of scientific merit, but which also has some regard to the needs of the science base of industry, and urge that universities will take due action in formulating their academic plans for the next ten years.

3.4.4 Royal Society Study of the Health of the Science Base

3.4.5 At the invitation of the Advisory Board for the Research Councils, the Royal Society embarked on a study in 1984 of the health of basic science in Britain. The exercise will concentrate on two broad areas of basic research of far-reaching scientific, and, ultimately economic importance. By looking at trends over the last 20 years, an attempt will be made in the study to assess the health of basic science in the two areas in absolute terms and by comparison with the performance of other countries. Resources made available for basic research (inputs) and the products of basic research (outputs) will be examined. The anticipated completion date for the study is the end of 1985.

3.5. Study by the Science Policy Research Unit

3.5.1. Before embarking on the task set in our remit by ACARD we considered it necessary to make some enquiries initially on how organisations in other countries went about the business of identifying emerging areas of science which at the time showed potential for significant economic development in the future. We therefore invited the Science Policy Research Unit of Sussex University to undertake a study to review previous appraisals of scientific developments that showed long-term (10 years or more) promise of commercial exploitation. The principal objective of the study was to report on:

i. assessments, which had been carried out in the last 20 years, of scientific developments that showed promise at the time of the assessment of leading to technological developments of economic significance;

ii. the role which the assessments might or might not have played in such developments;

iii. retrospective studies of significant technological developments to trace the science on which they were founded and determine whether any predictions could have been made of the economic significance of the basic science;

iv. the techniques that might be employed in a study of exploitable areas of science undertaken under the auspices of ACARD.

3.5.2. The study covered four major industrialised nations, namely, the United States, Japan, France and West Germany. Sources of information included large science - based firms, national science and technology organisations, Government departments and agencies, and technical consulting firms. The professional and academic literature on assessments (including techniques) were also reviewed in order to provide an insight into whether and how scientific advance had been identified in terms of its subsequent development into successful or unsuccessful technology. Information from organisations visited was obtained by means of detailed structured interviews (a technique developed by SPRU) at senior levels, to discuss the methods used for monitoring and forecasting science and technology. SPRU also had available comprehensive large-scale computerised databases on national science indicators, patent counts, and significant innovations, developed to further the understanding of the linkages between science and technology, and for predictive purposes.

3.5.3. We have not included the full report of the SPRU survey. The findings were reported in the form of a book published in November 1984. However, we summarise here the main conclusion of the study and comment on it again later in the report.

3.5.4. The main conclusion was that "the United Kingdom should attempt to bring the level of its long-term scientific and technological foresight activities up to that found in Japan". The "desirability of integrating, as the Japanese have done, the forecasting efforts of Government funding agencies, and industry, something which can only be achieved by drawing in wide sections of the research community" was also emphasised. A set of "guidelines" to improve national "macro-level foresight activity" in science was proposed.
The report by SPRU contained detailed commentary explaining more fully the rationale behind the guidelines and those seeking detailed information on the system proposed are commended to read the book.

3.6. Our Approach to the Identification of Exploitable Science

3.6.1. The SPRU study indicated, that of the four countries studied, Japan had a more committed approach to forecasting than had the other countries and detailed scientific assessments had become accepted as an essential component of national and industrial R & D strategy. Also, Japan tended to make longer term projections than did other countries. The approach, based on that used in Japan proposed in the SPRU study contained many features to which we were attracted but we felt that it was not completely appropriate for the circumstances which existed in the United Kingdom. The SPRU report recognised that it would be argued that the Japanese approach might be incompatible with British traditions in R & D planning but firmly believed that such an approach was necessary in the UK. Nevertheless, we considered that the inherent differences between the two countries in R & D organisation and management were sufficiently great to require some modification to the proposals made in the SPRU guidelines, for the purpose of this study. For example, the proportion of research carried out by the private sectors is much higher in Japan than in the UK, and the recent recessionary trends had less impact on Japanese industry. The research base in the UK is spread across a wider range of organisations each with varying objectives. Perhaps our clearest impression from the SPRU findings in Japan is that the Japanese showed almost a total dedication to their forecasts, irrespective of their quality and by such commitment made them almost self-fulfilling.

3.6.2. We believed, therefore, that it was possible to develop an assessment of scientific areas with potential in the UK using the approach outlined below but in order to obtain a commitment to such forecasts on the Japanese scale, changes in attitudes were required which largely depended on three factors:

i. a longer term view of scientific innovation;

ii. co-operation and communication of information between competing commercial interests, higher education institutes and Government;

iii. acceptance of the consequences of major structural change.

3.6.3. Our views on the reason for Japanese success in technological forecasting are confirmed by a 1983 report on "A Case Study of Technology Forecasting in Japan" by Professor Dore of the Technical Change Centre. The report describes the highly effective process by which priorities were set in the choice of scientific projects in relation to the balance between technological potentiality and market prospects, but the success in achievement was based on a complete commitment by a "a consensus society" to the choices made.

3.6.4. We were attracted by the suggestion of circulating a questionnaire to the R & D community but were not persuaded to pursue this approach since it was uncertain whether the replies would contain the details on scientific activity necessary for a comprehensive assessment to be made. The possibility that an exercise based on a questionnaire, might be carried out at a later stage, has not, however, been ruled out. The approach which we decided to adopt therefore was to seek to obtain a range of opinions on areas of science with economic potential from scientific workers at the laboratory bench to leaders in the scientific community and corporate planners in industry. Information was also sought on social change, market and resource trends, overseas developments in science and technology, political, economic and trade considerations.

3.6.5. In order to obtain a broad spectrum of scientific and other views links were established with a wide range of knowledgeable people across the scientific/technological communities. Major forward-looking UK manufacturing companies and other organisations were approached in order to gain an insight into their thinking on the science which would present future opportunities and markets. Another perspective on the potential of science was also obtained through approaches to major science and technology institutions like the Royal Society, Fellowship of Engineering, and Research Councils. Each organisation approached was invited to form a small group consisting of, for example, an outstanding laboratory scientist, design engineer, research team leader, technical director, forward planner, economic forecaster, etc. In the case of the science and technology institutions the groups consisted of outstanding young scientists/engineers and scientists/engineers eminent in their particular field of interest. Arrangements were made for a pair of members of the Study Group to visit each organisation to hold a free-ranging and uninhibited discussion on scientific areas likely to have significant economic consequences. Such discussions took place over half a day or, occasionally, a full day. At the outset of each meeting it was stressed that information given would be treated confidentially. A report on each meeting was produced and forwarded to the organisation for their comment/amendment or further elaboration. This process of consultation has involved a considerable body of people and allowed collection of information at a level of detail which might not have been possible by circulation of a questionnaire.

3.6.6. We would not wish to give the impression that the consultation meetings were completely unstructured. Careful consideration was given to the approach to take in the discussions and a framework of questions was drawn up to ensure that the major interests of the study were covered, and that themes were broadly similar from meeting to meeting so that comparisons could be made. The major theme questions were as follows:

a. What do you consider to be the most important areas of science likely to realise future economic returns within a 10 year and a 20 year time-scale?

b. In the case of industrial companies,

i. Can the main technologies likely to be used in your industry in the next decade and possibly the following decade be identified?

ii. What are the newly emerging technologes in your sector?

iii. What technical progress do you consider necessary in supporting sectors and is the rate of progress adequate?

c. Does the nation allocate its resources for scientific research properly, and can you identify unimportant areas of science receiving too much support and important areas receiving too little support?

d. How do you consider changes in markets and society will affect the directions of science undertaken by the country?

e. What are the methods employed for corporate planning of future research and development activities, and how and where do you get the data or information on the technical factors, markets, etc which you take into account when formulating long-term strategy?

f. Would a UK strategic overview of science be of help and made use of by your organisation in planning for the future and if so would you be willing to share that commitment with competing UK organisations against foreign competition?

A supplementary list of questions was also available for use in following up lines of enquiry. Not all questions were relevant to some organisations and in practice a flexible approach was taken in using the framework of questions during discussions.

3.6.7. In order to obtain information an area of science with potential being developed in other parts of the world, approaches were made to the Scientific Counsellors in major industrialised countries seeking their assistance in providing information on the scientific technical-commercial scene world-wide so as to identify exploitable new scientifically-based developments which offered potential market applications in the various industrial sectors. The sources for such information included overseas companies, national statistics, universities, scientific conferences, symposia, technical literature, data on market sizes/growth rates, competitive situation, etc.

3.6.8. We also collected a wide range of published material on contemporary science in the research literature, Government statistics and data on R & D, research plans of organisations, and relevant consultants studies.

CHAPTER 4 - A PROCESS FOR EXPLOITABLE SCIENCE

4.1.1 In this chapter we are concerned explicitly with the process by which exploitable areas of science might be identified and commercialised to the benefit of the UK. The overriding conclusion which we draw from our deliberations is that a process be established with the twin objective of (1) gathering information and identifying exploitable areas of science and (2) creating a commitment to translate exploitable science into technology in order to realise commercial processes and products. Although the picture we have obtained is incomplete because of the resources at our command, the impressions are sufficiently clear and revealing to indicate that action must continue in order that the scientific community can strengthen and increase its contribution to the national technological effort. We see greater commercialisation of the results of scientific research as being of the first importance both to increasing the international competitive strength of UK industry, and to increasing the long term resources available to support science in the UK.

4.1.2 We have not considered the study to be one of picking winners. Rather, we consider that the primary concern at this stage is the need to establish a framework for science decision-making, from which winners are more likely to emerge via market-driven processes.

4.2.1 The report prepared for us by SPRU argued that a major contributory factor in the markedly better performance of Japan over recent years in technology-based industrial sectors related to the difference in level of scientific foresight activities between Japan and other industrialised nations. Although SPRU pointed out that the Japanese approach took insufficient account, for example, of other dimensions relating to technological and industrial development and we have suggested that basic cultural differences and differences in R & D organisations obviate against the wholesale adoption of Japanese methods, we are firmly convinced that the fundamental principle is sound. With growing competition in the world industrialised markets and increasing technological sophistication of the products in those markets, most industrialised countries require a strong science based economy, decision-making procedures on national science policy must balance judgements on scientific and technical potentials against social and economic developments. The French are developing for their own needs a system similar to that of the Japanese by setting up an international network based on the Centre de Prospective et d'Evaluation (CPE), located within the Centre Nationale de la Researche Scientifique (CNRS), to assemble relevant databases to assist in the process of long-term scientific and technological forecasting.

4.2.2 During the course of our visits we have heard a number of opinions and views on the way that science policy is devised in the UK, and it is clear that present arrangements are not entirely satisfactory to many of those consulted, particularly in the private sector, who depend on the underpinning science and output of scientific man-power from the public sector. We referred earlier in Chapter 2 to the part which internally and externally motivated criteria should play in considerations of nationally important areas of strategic science. Internally motivated criteria are those traditionally associated with the peer review system which is driven by a process geared to the pursuit of knowledge, and intellectual challenge in which the recognition of successful achievement is largely in scientific publication or academic peer esteem. Left to itself, such a system does produce externally exploitable work, but often the effects are random and exploitation is a by-product arising fortuitously rather than by judgement. Moreover, the peer review system is particularly weak at exploring the interfaces between different, established branches of science and it is at the boundaries that significant commercial prospects often lie. If science policy is to <u>increase</u> the chances of producing advances in understanding which are of industrial and social significance, which at the same time generating substantial intellectual challenge, then that policy must be based upon information and criteria internal to and external to science. Strategic science policy will be facilitated by identifying the range of opinions relevant to the allocation of resources, by science judgements which seek to match scientific opportunity with social and commercial needs over a variety of time-scales.

4.2.3 In every country, science policy is selective insofar as science must compete with other claims on the public purse. Wealthy countries, in particular the USA, can afford to treat the commercial exploitation of science as a random process. An internally directed approach to science policy making is often wasteful of resources with frequent duplication of effort in different branches of the research system, and for the UK, the consequences of this approach are no longer sustainable. The objective of strategic policy should be to develop the science and technology to the point at which it can be rapidly and effectively assessed and exploited when market opportunities present themselves. We are convinced that it is feasible to identify the relevant range of opinion through a process of wide consultation and assembly of relevant data. The identification of opinion should involve a continuing dialogue with researchers (new and established), research allocation organisations (Research Council committees) and the industrial research community which iterate between areas of science with promise and those priorities identified by the providers and users of research funds. Above all, though, the process should be continuous. <u>We recommend therefore, that a process should be established for identifying exploitable areas of science, which has some certainty of continuity, for the long-term economic health of the country.</u>

4.3 <u>The Structures and Resources in Support of Science Policy</u>

4.3.1 In order to achieve the objective outlined above, we consider that four key elements in the process are:

a. the gathering of information on a continuing and permanent basis and its communication to the relevant parties and bodies;

b. the evaluation of relevant opinions and information, and the identification of exploitable scientific areas;

c. the allocation of resources to the priority areas in science;

d. the commitment to exploit the results of science to UK benefit.

Such information gathering and distribution would be a two-way process allowing continuous comment and refinement by the scientific community. Broadly based decisions would carry conviction and practitioners as well as potential users would become part of the process. We believe that this would enhance their commitment and confidence in the process. We also believe that this offers the greatest possibility of success in the UK context.

4.3.2 We have concluded that the information necessary to identify exploitable areas of science is acquired at present in a fragmented fashion in the UK. A number of bodies such as ACARD, the ABRC, Royal Society and UGC, together with industry all play a role but rarely do they interact as a combined force to shape policy and direction. This highest establishment of science requires to link much more closely and the degree of overlap between the bodies increased, in order to more effectively harness the talents available in them to the better direction of the research effort in the UK. Both ACARD and the ABRC tend to operate in a reactive mode and the Research Councils and universities are tied to a system of narrow functional committees in the former case and Departmental boundaries in the latter. A structure is required which can gather, analyse, prioritise, and direct relevant information into the decision-making machinery. The decision-making process must recognise the three spheres of activity, scientific, technological, and commercial. The structure should link with other bodies, such as the Requirement Boards of DTI and the appropriate scientific bodies of other Departments and organisations.

4.3.3 We do not propose that new arrangements are necessary for the mechanisms of funding science. In order to generate a process for identifying exploitable science resources will be needed to design the database and to provide judgements on the quality of data. We envisage a small management group to steer the process of identifying exploitable scientific areas independent of the bodies directly concerned with the management of science budgets. Responsibility for information gathering and communicating within the broad scientific community, would be carried out by a body or bodies preferably located within an established institution which held the necessary hardware in terms of computers and access to information both from databases in the UK and from around the world.

4.3.4 If such a process is to be effective in achieving change, it is essential that resources put into R & D must be translated into industrial products, entrepreneurs in science must be brought together with entrepreneurs in industry. That linkage should be intimately concerned with identifying areas of science with potential, marshalling resources, and executing programmes. The first report of the House of Lords Select Committee on Science and Technology (Cmnd 8591) expressed concern that there was too rigid a distinction between basic and applied research and this was noted by Government in their response to the report; the response also suggested that ACARD and ABRC should review the links between basic and applied research. We concur with that view and would wish to see a more pluralistic approach to science funding, flexibility should be built into funding mechanisms to allow research programmes to be built up and ended. We discussed briefly in Chapter 1 the relationship of our exercise with the Annual Review of Government-funded R & D, and referred to comments in the Select Committee's first report that the Annual Review analysis should "not be a facile choice of areas where more money should be spent" .... "skillful value judgements as to allocation of financial and manpower resources are, however, needed. This will involve distinguishing between vital and dormant areas, identifying gaps, disparities and duplications, and considering the opportunity cost of relinquishing certain areas of research. The emphasis will be on review of long-term plans". The Annual Review process is well established and we believe that it should now consider long term R & D plans.

4.4 The Nature and content of Research and Development

4.4.1 The process outlined above should in time lead to a more rational allocation of resources to these science areas of prime national interest. This will require changes in emphasis in the scientific efforts of universities in order that their scientific resources matched perceived priorities. A mechanism is needed for attracting students to scientific areas of economic promise with intrinsic growth potential. Consideration may be needed of the wider balance of disciplines in the universities. As frontiers expand in new areas, old subjects may be overtaken, for example, and university structures need to keep pace with the rapid advance of knowledge.

4.4.2 We recognise that some areas of science are of potential importance not because of their relevance in terms of direct market applications, but because of other factors such as Government policy, legal constraints, public pressure, etc. Such areas relate particularly to health care, defence, the environment and consumer safety. There are also areas of science and technology which have important social implications, for example, the increasing desire by women for both careers and families and the technology which might assist in the fulfilment of those needs. Society itself creates pressures requiring a scientific or technological response and may also have a direct effect on the process of innovation itself. Thus the current pressures towards alternatives to animal experimentation will have a direct bearing on the science of health care. There is also little doubt that public concern about environmental issues will increase in the next 10-20 years in the UK, rather than diminish. The scientific issues are complex, but such concerns require a reasoned scientific response to avoid the possibility of serious economic consequences and misguided solutions. Careful consideration will be needed of which scientific areas in the environmental field are essential to the UK and which can be left to the international scientific community; for example, geological science may be relevant to waste disposal in the UK but the "Greenhouse effect" is of international interest. The area of product liability has attracted considerable investments in R & D by the private sector in recent years. <u>It is our view that careful and selective attention should be given to non-market forces which will have significant impact on acceptance by society of change and science/technology.</u>

4.5 <u>Industrial R & D Priorities</u>

4.5.1 The major manufacturing companies in the UK have quite sophisticated techniques for developing a foresight of science which will be of relevance to their future and are also able to obtain further insights by commissioning studies with consultants. We have the impression, however, that wide-ranging foresight activities are required at lower levels in the R & D system. The SPRU study suggested that Government should stimulate such lower level forecasting by the provision of incentives (financial or otherwise). We agree that such forecasts are necessary but do not see a role for Government and propose that industry itself should set up the mechanisms for undertaking long term research forecasting on a permanent and routine basis.

4.5.2 Attention was drawn by SPRU to the need for comprehensive data on the inputs to research, and output data in order to develop sophisticated forecasting techniques. Regular and detailed statistics on R & D in firms, universities and the Research Council institutions are required. The Annual Review of Government-funded R & D is beginning to provide comprehensive statistics on public sector funding of R & D. Some information on industrial R & D support is available but is far from comprehensive both in terms of coverage and detail. Nor does the UK possess the large indigenous data-banks on science and technology, patents, etc available in Japan and the United States. The UK does not possess the large number of "think tanks" capable of undertaking assessments of science and technology which the USA and Japan possess. UK databases on science and technology tend to be too academic in nature and appear to be geared primarily to the needs of the specialist researcher than to the broader requirements of industrial research, development and exploitation.

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PART II AN INVESTIGATION OF EXPLOITABLE SCIENCE IN THE UK

CHAPTER 5 SOME ELEMENTS OF SOCIAL CHANGE

5.1. The last two decades have witnessed a period of rapid change in UK society and even more rapid change in world society. Such change is the result of a wide range of economic, social, international, political and technological forces. It is not within our competence, however, to attempt to draw conclusions for technological development about the interaction of such forces but clearly broad changes in society and social attitudes are a significant determinant of the rate and direction of technological and industrial development. For example, information on population will assist in determining potential market sizes, and societal attitudes and age structure perhaps, acceptance of new ideas and technologies. Similarly incomes, employment rates etc are relevant to ability to purchase products of innovation, new processes, etc. In this chapter, therefore, we discuss some of the social factors which we consider to be of importance with respect to the exploitation of science in the future. We have not considered the more detailed question of how the social sciences can help in the application of science and technology, but we believe that there are two particular areas which need to be addressed by the social sciences. One relates to the social acceptance of technological change, and the other to the changing needs of society in relation to demographic change. We refer to these in more detail later in the chapter.

5.2 Demographic and Other Trends

5.2.1 Information on social change and some predictions on future trends are provided in official statistics. The following table gives a broad picture of recent change

Table UK Demographic and Social Changes

	1961	1981	2001 (projected)
Population, millions	52.8	56.4	57.6

Aged 65 and over, millions	6.2	8.5	8.8
Aged 75 and over, millions	2.2	3.3	4.1
Birth rate per 1000	17.8	12.6	
Average number per household	3.09	2.71	

(Source: Social Trends 15, 1985)

In terms of total population, UK numbers are projected to rise by about 1 1/2millions by the end of the century, although others like the Henley Centre have forecast little or no increase. Perhaps the dominant theme in population over the recent two decades has been the increase in the number of elderly, thus there were 2 million more people of pensionable age in 1981 than in 1961. Such numbers are not expected to increase further in the next 20 years, but the population of very elderly ie 75 years or more, will grow dramatically to the end of the century with consequent effects on health and social provision. In terms of the population of compulsory school age, numbers will continue to fall over the remainder of the decade which has implications for the education field and in subsequent years on job provision and higher education. However, the pre-school population is presently growing which will have consequences for the public services toward the end of the century and beyond.

5.2.2 Official figures also reflect marked changes in households and family composition in recent years. Striking features of such changes are the doubling in number of people living alone in the last two decades, the increase in single parents with dependent children and decrease in average household size. However, the figures demonstrate a relative stability in the dominant type of household in the UK, namely that headed by a married couple, which formed 78% of households in 1981 compared with 82% in 1961. The marked fall in household size has resulted from a proportion of single parent families because of the increasing divorce rate and elderly living alone, and the fall in birth rate resulting in smaller family size. In the next decade, the population aged 30 - 44, ie those responsible for family formation and high consumption groups will increase significantly and could provide a force in the marketplace to stimulate the demand for new technology and products.

5.2.3 Such broad trends are of importance to planners of social and public services and the more detailed changes taking place within the wider changes are of vital interest to market analysis and product/process planning. However, our main concern is the major changes taking place in relation to the principal industrial sectors and social attitudes. In the next few passages therefore we consider briefly the trends which will have a more direct bearing on technological and industrial progress, for example, employment rates, attitudes to work work forms and attitudes to change and technology in society as a whole.

5.3 Employment rates

5.3.1 An outlook on numbers of people available for employment was published earlier in 1984 by the Department of Employment. These may be summarised as follows

Table Employment trends in the UK

	1971		1981		1991 (projected)	
	M	F	M	F	M	F
Civilian labour force, millions	15.5	9.3	15.6	10.5	15.8	11.0
Activity rates, %	80.4	43.8	76.5	47.3	74.9	48.2
Unemployment, %	3.4 (total)		10.0 (total)			

(Source: Department of Employment)

Although definitions in relation to official statistics on employment have changed in recent years, the broad trends indicate that in the 1970's the labour force grew at about 1/2% per year with a slightly lower increase through the 1980's and this will level out in early 1990's. The dominant trend in the recent decade has been the increase in the age of the working population and a falling activity rate in men, reflecting a growing tendency to take early retirement and decreasing likelihood of working after retirement. In 1982 some 92% of men over 65 were retired compared with 68% in 1959. The rising trend in female activity rates in the last 3 - 4 decades slowed in the mid-seventies although the increase is projected to increase at a lower rate to the end of the decade. The increasing numbers of working women, a higher percentage in the UK than in the rest of Europe, is an important feature of our changing society which will have major implications for work forms and employment patterns. Indications are that economic pressures will continue to encourage some movement to early retirement, but the trend will slacken in the mid-1980′s. Economic conditions have a stronger effect on female activity rates than on male rates and such rates are expected not to continue to rise as quickly as past rates.

5.3.2 Problems have been created by the desire in modern society for both spouses to have permanent careers in full-time or part-time employment. Such problems at present concern difficulties in acceptance of promotion or more senior positions in employment and in seeking employment which is more rewarding or gives greater job satisfaction, because of the effect which this might have on the employment position or job satisfactin of the other spouse.

5.3.3 An important component of a society which is adaptable is the mobility of people and creation of conditions which allow easy and efficient movement whether for purposes of change in employment or other reasons. However, obstacles exist to such movement in the form of complexities of buying and selling houses (more in England than in Scotland) and the tendency for Council houses to be available only to long-time residents. Compared with other European countries, the UK is in a uniquely inferior position in terms of the availability of satisfactory housing for rent particularly at the junior professional level.

5.3.4 Employment in the major economic sectors are shown in the following table

Table	Employees in Employment in the UK (millions)		
	1961	1971	1981
Agriculture, Forestry and Fisheries	0.71	0.43	0.35

Mining and quarrying	0.73	0.40	0.34
Manufacturing	8.54	8.06	6.09
Construction	1.48	1.26	1.14
Gas, electricity & water	0.39	0.38	0.35
Services	10.38	11.60	13.43

(Source: Social Trends 14, 1984)

Even in 1961 the services sector employed more than the manufacturing industries but the gap has widened rapidly and now two people are engaged in services to every one in manufacturing. Practically all areas in the services industry have increased their share of the workforce with only transport and communication showing a small decrease; women accounted for 54% of the workforce in the services sector in 1982. The other major industrial sectors which have experienced the greatest falls in employee numbers are agriculture, mining and quarrying and to a lesser extent construction. In the manufacturing industries, employment in metal manufacture and textiles, leather and clothing have declined by more than 50% in the last two decades. In the services sector, some 30% of employees were working part-time, compared with 24% in 1971, but far more women were working part-time than were men, 10% and 47% respectively in 1981. Only 7% of employees were working part-time in manufacturing industry in 1981.

5.4 Attitudes to work

5.4.1 In September 1984, the Aspen Institute of Humanistic studies published an interesting report on "Work and Human Values" which sought to address two issues: one concerned problems in industrialised countries related to workplace such as unemployment, slow productivity growth, skills mis-match, low ability to manage people, poor motivation, and the other that the problem could not be understood from a purely economic perspective. The premise behind the study was that industrialised countries were now facing a harsher and more competitive economic climate in the world, but societal values had been shaped in times of less economic rigour and there was less willingness on the part of society to sacrifice benefits obtained earlier for economic objectives. At the same time, new social values had emerged, particularly among younger and better educated people which placed great emphasis on values such as creativity, independence, suspicion of authority, self-expression, pleasure and new experiences, search for community involvement in decision-making, quest for adventure, closeness to nature, cultivation of self, and inner growth, at the expense of status, material values, wealth, acquisition,etc. Such values were also being transferred to the workplace, and in the USA there was clear evidence that, recently, fulfillment of such values was satisfied for younger people more in the workplace than in leisure. It was suggested that in the 1960's and 1970's such values had initially led to demands from the workplace in terms of right and benefits for less in terms of quality, effort and commitment. Economic events also apparently had little effect on these values as people appeared determined to adhere to them even if economic viability was affected.

5.4.2 The Aspen report compared six countries, UK, Germany, Japan, Israel, Sweden and the United States in relation to social values and attitudes to work mentioned above. A major finding common to all the countries studied was that work was no longer perceived as a necessity to be undertaken for survival purposes, but as a means of achieving certain psycho-social benefits as well as monetary reward. New jobs being created in all the countries were more challenging and rewarding. This development had important implications particularly for those unemployed, creation and location of new jobs, synchronisation of preferred lifestyles in relation to rewards of work, etc.

5.4.3 Another important conclusion was that present incentives tended to reflect past industrial systems when individual incentive counted for less and people had less discretion and decision-making influence over their jobs. However, with increase in the service sector and replacement of routine operations by technology, discretion on work performance is increasing in all the countries surveyed; but the report also indicated that enhanced discretion had not been matched by improved economic performance. It was suggested that in the industrialised nations dependent on a stock of skilled human resources for competitiveness, a reconsideration of the incentive system was required. Employment should offer greater opportunities particularly for younger people of entrepreneurship, creativity, autonomy, challenge, the development of new skills, social interaction, individual achievement and personal recognition. These requirements apply no less in scientific fields as in any other field.

5.4.4 The survey also addressed the issue of work ethic and economic vitality in the countries studies; of particular interest was the relationship between the quality of the job and the commitment to it. Thus if jobs were repetitive, unrewarding and dehumanising, it would be difficult to increase commitment to work itself. In the countries surveyed, the move to upgrade the quality of jobs was strongest in the US, and in the various countries, the UK had the highest proportion of jobs perceived to be least likely to attract commitment. "Work ethic" defined as an attitude which endowed paid work with positive meaning and equated self-worth and satisfaction with the quality of achievement in work, was also compared in different countries. In the USA, more than half US workforce (52%) according to the sample surveyed endorsed a strong work ethic compared with 26% in West Germany and 17% in the UK.

5.4.5 Japan has been highly successful in obtaining an industrial consensus to work together towards common industrial goals. This attitude prevails to a lesser extent in US industry, in contrast with West Germany and the UK which demonstrated the least commitment to a consensus approach. On the other hand encouragement to self-employment and entrepreneurship appeared to be more attractive in the UK context; recent manpower training systems have emphasised such options. The promotion of those options were seen to be important in relation to the part which new technology might play in stimulating new economic activity. Technology in the past had favoured large scale operations, but increasing penetration of information technology into economic activities allowed more scope for small-scale decentralised operations.

5.4.6 Issues relating to access to employment by young people were also addressed. It was suggested that some industrialised countries had been training too few people in the skills required by modern industry, and the training was too inflexible and lengthy. The situations in the UK and West Germany were compared. Investment in graduate manpower was some three times greater in West Germany than in the UK. Also, about 60% of the West German workforce gained a vocational qualification compared with about 33% in the UK. Whereas 44% of school leavers in the UK started work without further training, only 7% did so in West Germany. The West German apprenticeship schemes were nearly three times as costly as those of the UK and twice those of the equivalent in France. The report suggested that UK industry had suffered from under-investment in people, and that the UK educational system tended to under-rate engineering and technology compared with the humanities. Pay differentials were also another factor. In the UK a policy was needed for "the development of an integrated national policy for the development of experience and flexible skills at all levels", because of "the low reservoir of technical skills and the widening gap between education and industry".

5.5 Work Forms

5.5.1 Social values described in the foregoing have a direct bearing on demands for organisational structures and operations. Most hierarchical structures, structured on objectives related to increasing turnover, profit and return on investment, for instance, are founded on the assumption that people in organisations wish to rise through the hierarchy. This type of work form is beginning to be questioned.

5.5.2 The opportunities presented by smaller, decentralised operations in the UK based on new technology was referred to earlier. This would require promotion of entrepreneurship, but the Aspen report suggested that the tradition of entrepreneurship and acceptance of risk was not so strong in the UK as in the United States, for example, and particular effort in the way of specific programmes of intervention to stimulate entrepreneurship and self-employment would be required. Another approach to increasing opportunities for greater economic activity suggested for West Germany was to focus on the long term, and the informal economy which existed outside the formal economy. It was suggested that for countries with a strong work ethic, like the USA and Japan, an increase in the size of the formal economy was the most viable response. But in West Germany and perhaps the UK where the work ethic was not as strong, enhancement of the informal economy was seen as a way of avoiding societal polarisation as jobs in the formal economy were shed due to increased penetration of technology. Attention was drawn to the fact that in West Germany, there would be little resistance to a move from full-time work to a form of work which was less rigid in its time commitments, more autonomous and more dedicated to the pursuit of non-materialistic values. Mechanisms such as job-sharing, part-time work and extended job sabbaticals were suggested. It was also proposed that many jobs that served the community which were now situated in the formal economy, might be transferred to the informal economy and in doing so might be upgraded in order to increase the value orientation and be more socially rewarding for those involved.

5.5.3 These general trends in work-forms and attitudes to work will have important consequences for the scientific community. The ageing of the scientific population has been commented on by others and is of particular relevance to the scientific process which demands constant inputs of new creative thinking. Mobility of people in society referred to earlier is of relevance to movement within the scientific community. Lack of flexibility in the careers of scientists related partially to the career structure, institutional organisation in science, and the compartmentalisation in institutions, are an additional obstacle to the movement of scientists and also serve to reduce the oportunities for joint work, interaction, collaboration and exploitation of science and technology. Historically, science has been most creatively productive when scientists have moved freely within their community, thereby optimising the opportunities for cross-fertilisation of ideas and disciplines. Such movement encourages the constant formation, dissolution, and reformation of small informal scientific groupings able to generate the creative force and enthusiasm to push forward scientific frontiers. The large formalised scientific groupings which have tended to develop in the present institutial framework have been of value in progressing large state-of-the-art science problems but many such groupings have bec[illegible] inward-looking, as the broader curiosity-driven approach has been diminished and individual initiative to exploit science and technology reduced by overall institutional requiments. Urgent attention to this problem is needed and an environment created in which small informal scientific liaisons, able to change and react to change as new scientific and technological opportunities arise, are encouraged.

5.6 Reaction to Change

5.6.1 In order to obtain an impression of how society reacted to advances in science and technology and gain an insight into receptivity to technological change, we commissioned a study with the Taylor-Nelson Group on the implications of social change for technology and industry. The following passages summarise the main findings of the study.

5.6.2 The report started from the premise that technology development, or the development from invention to innovation resulted from demands by society, and that most technology in the industrial era was developed to satisfy needs of material wealth and comfort. But more recent market influences related to requirements for more time, more freedom, more choice, more opportunity for learning, etc. The technologies which might satisfy such requirements, were likely to be smaller scale, more personal, high technologies, to enhance work and leisure, to improve the quality of life and workplace, to facilitate education, improve health, etc. If such a trend had in fact become established, choices had to be made on whether effort should be concentrated on science and technology more appropriate to this trend or attempt to hold on to the technologies of the industrial era which were likely to become less competitive. It was natural, because of the past investment in industrial technologies, plant and equipment, that there would be a certain reluctance to change. Our comment on this would be that in reality the choice would not be quite so black and white; it would be necessary to reconsider certain traditional industries because they themselves would be prime targets for new technology and could be catalytic in development of new technologies and industry.

5.6.3 Attitudes to technology were considered by collecting market surveys over a number of years related to issues of concern, belief, attitude, correlated with actual behaviour. Issues in the surveys relevant to science and technology were:

1. scientific breakthroughs and new technology are our main hopes for a better life

2. we should accept some pollution if we want to maintain industry and our standard of living

3. welcome technological advances for everyday living

Responses to each of these were as follows:

	1	2	3 %
Strongly agree	13	5	11
Agree	47	36	47
Neither	26	22	23
Disagree	11	27	15
Strongly disagree	2	8	2
Not sure	2	2	2

The conclusion drawn from the responses was that a majority of people favoured new technology but some large minority groups were sceptical about technological development. Greater sceptism was expressed about acceptance of pollution in order to maintain industry and standards of living. It is not possible to give full details of the survey here which considered such issues in relation to various societal groups; for exampe, social value groups concerned with self development and personal growth, and those with more traditional, conservative, conventional values were more doubtful about the value of technological and industrial growth whereas those concerned with reward, status, economic security were more protechnology.

5.6.4 It was also suggested that single issue (pressure) groups, which espoused a single cause to exclusion of all else, could increase their influence on technology and industry development. A genuine problem was perceived by some social groups, who were concerned with potential problems associated with technology, and it was concluded that the evidence indicated that single issue groups were likely to become more effective and cover wider ranges of issues in the future.

5.6.5 Attitudes to industry were also considered. The following figures show responses to questions on whether industries influence on the way of life in the UK was for better or for worse.

Table Industries Influence of Way of Life in Britain

	Better	%	Worse
Engineering	86		2
Gas	76		4
Oil	77		6
Nuclear	41		33
Chemicals	49		24
Coal mining	59		12
Electronic/computing	87		4

Without having detailed information on why particular responses were made it is only possible to comment generally. Presumably, attitudes on the nuclear industry are a reflection of the current national debate about nuclear matters generally, and some ambivalence about chemicals due to recent problems with chemical plants more in the other parts of the world. Perhaps the main conclusion that may be inferred from these data is that there appears to be a loose correlation between confidence in the industry and perceived safety of the industry itself.

5.6.6 In summary, the main conclusion was that change is not readily achieved in the UK. As in all populations, certain groups are more likely to accept change than others. About 30% of the adult population, more often than not the better educated, socially active, liberal in attitude, interested in self-knowledge, creativity and self-confidence, are the segment of society most willing to accept change if it fitted in with their values, attitudes and lifestyles. Roughly another third of the population who are either more traditional, conservative and conventional in their views with strong sense of morality, personal integrity, responsibility, family loyalty, or are interested in acquisition of material possessions, financial remuneration, status, self-improvement tend to react positively but slowly to change if it benefits them or suits their objectives particularly in regard to wealth or status. The remainder of the population appear to be made up of a group which is the largest as a whole, who are not socially aware or interested in self-improvement or self-development, are consumers, home/family orientated, and reject change, being wary of new technology and developments, but will eventually accept change if the rest of society does; and a group with limited financial capabilities who are either disillusioned with institutions, constrained by their circumstances, prefer stability, and fear change or are demoralised, aimless, resigned, apathetic, sometimes violent, reactionary in social and political views, distrustful and are distrustful of technology and change.

CHAPTER 6 - TECHNOLOGY: THE BRIDGE BETWEEN MARKETS AND EXPLOITABLE SCIENCE

6.1.1. We have arranged this chapter around the theme that technology acts as a bridge between science and the production of goods and services which are valued in the market-place. Technology enables the promise of science to be exploited in ways which create employment and raise standards of living in general. Of course, we recognise that the links between science and its commercial exploitation are complex and not unidirectional, and that techniques are rarely fully developed when they are first introduced commercially. The typical history of an industrial activity involves a sequence of advances in products and processes, advances which are stimulated by market pressures and by opportunities opened up by new scientific developments. Furthermore, the extent of commercial application of any one technology depends on the technologies with which it is in competition, and it is often held back by a lack of development in complementary technologies. For the present purpose, we leave such issues in the background and focus upon trends in science, market needs, and technologies in a small number of selected areas.

6.1.2. Our use of the word trend needs to be clarified. The primary trends are those developments in science, economic, and social environments which alter the balance of relative commercial returns to the development of different techniques. Thus changes in the population, age structure and advances in greater knowledge are the primary trends which will greatly influence the commercial development of medical technology. Environmental attitudes on waste disposal will greatly influence the application of nuclear technology. Similarly, the persistent tendency of real wages to rise,and change in the availability of different materials and sources of energy continually generate new opportunities for technological development.

6.1.3. Induced patterns of technological development which reflect the primary trends may themselves be identified as trends - for example, more fuel-efficient aero-engine technology, more efficient measuring techniques, the displacement of paper based communications technology with electronics based communications, but they are secondary, consequential trends arising from the pressures and opportunities created by economic, social and scientific change. In what follows we shall be concerned almost exclusively with primary trends. ~~as a secondary trend in one sector of the economy may equally be viewed as a primary trend in another sector which competes in the same markets for inputs and outputs.~~

6.1.4. At this first stage of our analyses we have sidestepped many complex issues by focussing on these broadly defined primary trends. A more detailed identification of strategic promise in science would have to look in much greater detail at developments in particular markets, in the profitability of different technological solutions and the contributions which different sciences would make to those solutions.

6.1.5. In the following sections we have carried out an investigation of those factors relevant to strategic science:

a. Economic and social pressures affecting the returns from developing different technologies;

b. The technological solutions which are likely to arise in response to those pressures;

and c. The areas of science likely to underpin the required advances in technology.

The areas of science are presented in greater detail in Chapter 7.

6.1.6. The analysis deals mainly with the UK scene and markets. Such markets are similar to those in other developed countries. But the UK exports to markets which are markedly different such as those in newly developing nations, and although we have not been able to consider these here, we believe that any subsequent and fuller analysis must take these into account.

6.1.7. At the end of each major section we have included a schematic representation to illustrate the mutual interactions between areas of science, technology applications, and areas of economic activity. We believe that actual developments do not follow a simple linear sequence between these stages and a capsular model has been used to emphasise the mutual influence of spheres of activity. The core of each capsule describes economic activities which are currently discernable or possible, surrounded by an inner layer of technology applications broadly relevant to these economic activities, and an outer layer of the scientific activities from which new technologies in the marketplace will arise. Such a scheme is intended to show how commercially valuable technology arises from a combination of market forces and scientific advance. Relevant technology is described in the representations in two ways. Broad changes involving many technologies are shown in capitals and specific technologies are put in the lower case. Each capsule is not mutually exclusive to others, economic activity and technologies overlap in different areas; for example, communications and information technology will impinge on many market trends and technologies in the future. Therefore, for each capsule, a footnote is added pointing to other areas with associated trends, technologies and science which are relevant to the area described. Finally, we recognise that for some economic activities there is little associated science, although links with technology might be greater; such areas are apparent from the illustrations.

General Considerations

6.1.8. Various trends in society are so broad that they do not fit into any defined area of activity. We have discussed in Chapter 5, some social factors which have become apparent recently but other broad trends are more clearly discernable; for example, the increasing desire of people for autonomy, to act independently, and to have greater control over their own lives will affect communications and transportation technologies among others. At the same time, concerns have been expressed about privacy in people's lives and interactions which will affect the directions of markets and technology, and speed of exploitation of science. Other fears which were discussed briefly earlier relate to safety of the environment and acceptance of technology. We have referred in Chapter 4 to the growing impact of single-issue pressure groups in relation to environmental concerns but other pressure groups in society whether institutionalised or not may have unforeseen results on particular societal and technological developments. Thus pressure groups in the medical or dental professions interested in surgical as opposed to preventitive approaches to health care may set the pattern for medical research and development. Other groups, for example, in the legal and scientific professions or in particular business, industry, or trade are able to exert influence to determine particular social or technological directions.

6.1.9. Another major preoccupation or trend in recent years and one that is not likely to diminish relates to security and the way in which it impacts on society; this ranges from safeguard of the individuals and their rights or property to protection of a scientific advance or intellectual concept and various aspects of civil, national and international security. Such preoccupations have influences and will have consequences at many levels in the economy and society. The level of crime as indicated by the number of offenders recorded by official statistics , both male and female, found guilty of or cautioned for indictable offences has risen steadily over the last two decades. Highest rates of indictable offences occur in the teenaged population. Vandalism is by far the major form of crime of which only about 8% is recorded, followed by theft from motor vehicles. So far as notifiable offences are concerned, roughly half arises from theft and handling of stolen goods, and burglary accounts for another quarter. Motor vehicles are the most common target of crime. In terms of crime against property, inner city households particularly flats are much more vulnerable than households elsehwere. Concern about security has had a number of social, technological and commercial consequences. Thus private security companies have been a growth area, sophisticated security devices have been developed in response to a growing demand for equipment for protection of person and property. However, with the increasing penetration of electronic technology in the activities of business, industry and society generally the pattern of crime may change which will require further technological responses in terms of the security related to such activities. Also, with an ageing population safety consciousness in some daily activities such as driving may act as a spur to technology.

6.1.10. In 1982, consumers expenditure accounted for about 61% of Gross Domestic Product (GDP). The proportion of consumers' expenditure in various categories is as follows:

	% of total consumer expenditure at current prices		Consumers expenditure indexed at constant 1980 prices	
	1972	1982	1972	1982
Food	18.3	15.3	96	99
Alcoholic drink	7.2	7.3	79	94
Tobacco	4.5	3.5	104	86
Clothing and footwear	8.3	6.4	82	109
Housing	12.9	16.5	85	104
Fuel and power	4.4	5.2	94	98
Household goods and services	8.0	6.8	99	104
Transport and communication	14.4	15.8	92	103
Recreation, entertainment and education	9.0	9.3	75	105
Other goods, services and adjustments	13.2	13.8	90	99

(Source: Annual Abstract of Statistics)

Within the categories shown major changes have taken place. For example, real expenditure on clothing and footwear increased by 33% from 1972 to 1982, and on post and telecommunications by 73%. The sharpest rise in real expenditure was that for television and video recorders which showed an increase of 133%, whilst that spent on recreation, entertainment and education rose by 40%. in terms of current prices the proportion of consumer expenditure spent on food has declined significantly in the decade from 1972 to 1982 and the proportion of expenditure on housing showed a significant increase. Spending on tobacco showed the most significant decrease in the last decade. Housing and transport and communications now form the major components of consumer expenditure contributing to GDP.

6.2. COMMUNICATIONS

6.2.1. Mechanical processing of numbers was first carried out in the last century and electro-mechanical devices made towards the end of the century. Although the first electronic calculating machine was built in 1946, it was in the mid-1950s that the processing of information became an identifiable predominant activity of working people. It has been suggested that it was at that time, certainly in the USA, that the industrial society gave way to a post-industrial society or society based on the production and distribution of information. Much of the so-called service sector, which has grown at the expense of manufacturing, is concerned with information activities, and much of manufacturing industry is itself involved in communication of information.

6.2.2. The availability of communication technologies and their widespread use, will permeate practically all human endeavours. Identifying characteristics of information processing techniques and devices will find applications not only for management, gadgetry and games but will have a profound influence on the pattern of life, through, for example, basic changes to the production and processing methods of industry, employment and leisure, economic and social development, and even the interaction between nations. Perhaps the key feature of the so-called information society is the controlled acquisition and accumulation of knowledge in communication systems and amplification of the processing techniques with which to use that acquired knowledge. The support of knowledge systems themselves thus becomes a major driving force of economic activity.

6.2.3. The proliferation of communication and transfer mechanisms will radically transform transactions between individuals and groups in society relevant not only to private services sectors of the economy but also to education public sector services, private communication, performance of functions and many others. One aspect of such development concerns the problem of public access to information, such as protection of privacy, for example, by the consent of individuals to the use of stored information and protection of data from external penetration of or internal leakage from communication systems.

6.2.4. Better communications will increase the possibility of working from the home, which might have some effect on travel and commuting. The ability to work, with the help of communications, from home will also permit growing numbers of women to continue working after starting their families. This trend, already strong in the field of software, may well spread to other economic fields.

6.2.5. One major effect of the growth in world communications technology will be the increasing internationalisation of business opportunities. Thus the satellite will allow information to be instantaneously distributed and shared around the world, with the possibility, however, for destabilisation to occur over the world's commercial markets rather than being confined to one particular market. Transactions and trading in goods and services round the world will result from an increasingly electronically based world business and commercial community. In money market terms the UK financial community might be well fortunate in being in a favourable geographical position to conduct business with the USA and Far East in the same day.

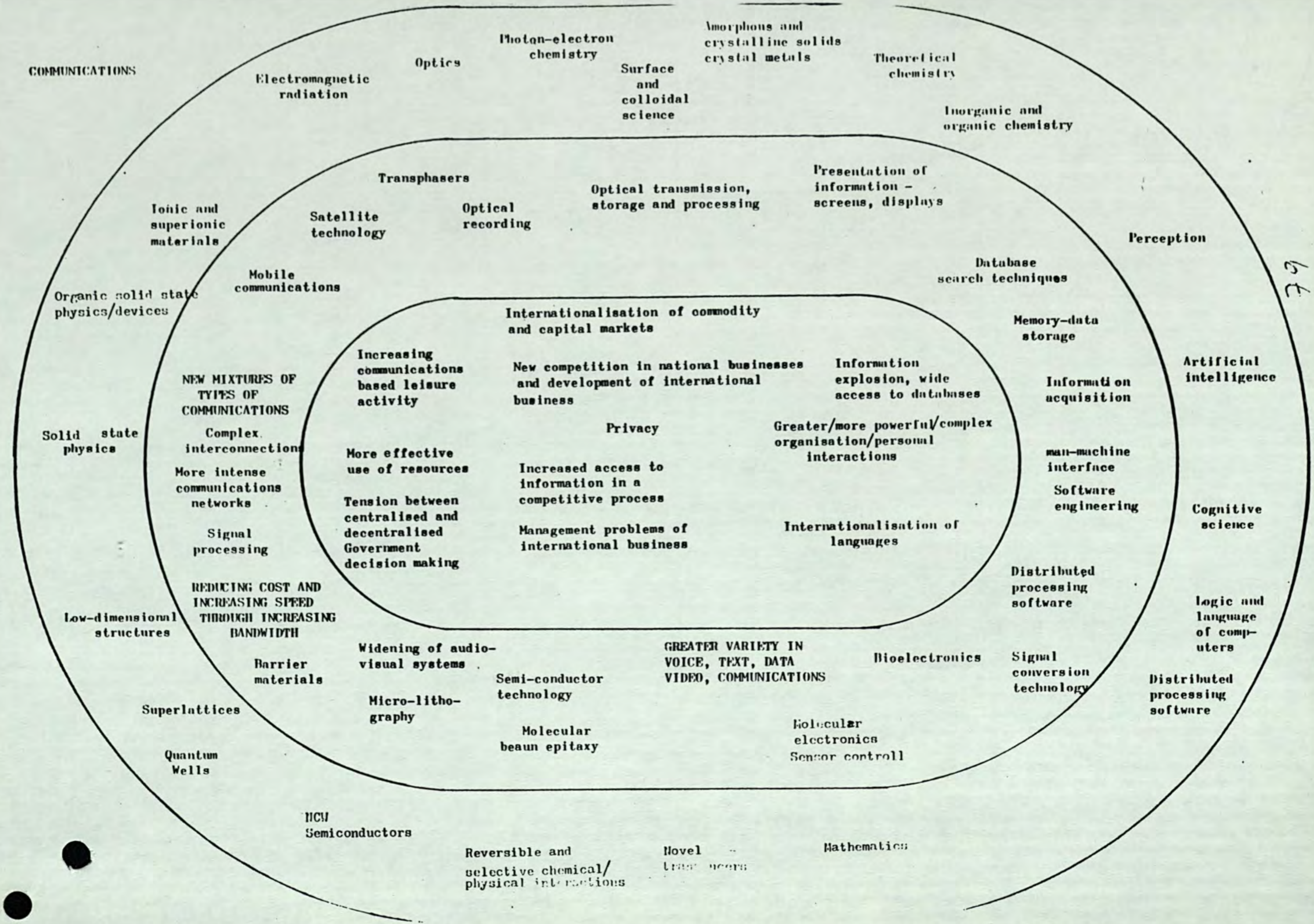
6.2.6. Video recording and transmission is in its infancy and business opportunities for future video applications in education, counselling, advisory service, selling, etc are clearly possible. However, technological innovation in communications is unlikely to proceed linearly and advances are likely to occur in fits and starts. For example, experiments have been started in electronic shopping and marketing but it is highly unlikely that people will wish to do all their shopping electronically although for some sections of the populations and for some transactions it will be advantageous to do so. Similarly teleconferencing will not totally replace the face-to-face business meeting, since it will probably be found to be inappropriate or inadequate in many circumstances.

6.2.7. Cable television also offers many options for development. Apart from delivering locally produced programmes such systems can produce a diversity of television communication ranging from business, religious, news services to health, childrens, scientific, art or other networks. Already in the USA cable networks are drawing audiences in the prime viewing times from the national television companies and it has been forecast that in the next decade such companies may well have only 50% of the total television audience.

6.2.8. The rate of change in communications technology has begun to impact at a local level on paper-based systems and will expand to dominate more widely distributed systems. As well as increasing the speed of flow through information channels and of transactions, the new technology is renewable and self-generating. However, because of such technology, information is being generated at rates unsurpassed in the past, and uncontrolled, unorganised information could impede the exploitation of the developing knowledge base. Developments in modern information technology will therefore have a vital role to play in the selection of information. On-line database technology will be essential to the wide availability of required useful information and dissemination of knowledge. Wider access to such databases will require development of much better software.

6.2.9. Global communications with a variety of objectives will be of increasing importance, and the satellite will have a key role to play. Satellite technology is advancing rapidly and now incorporate the functions of ground stations. As demonstrated recently the development of space shuttles for the retrieval and servicing of satellites will have relevance for the information economy as well as for space exploration.

6.2.10. Growth in communications may see greater internationalisation of national languages. It is unlikely that a world language will arise although English may be used increasingly as an international business and legal language. As the global economy becomes increasingly interdependent, national cultural and linguistic traditions may well be reinforced, as they have been in Europe since the formation of the European Community, but communications technology may provide, for example, the simultaneous automatic machine translation of national languages, for broadcasting worldwide, and ease communication between national communities.



COMMUNICATIONS

Electromagnetic radiation

Optics

Photon-electron chemistry

Surface and colloidal science

Amorphous and crystalline solids crystal metals

Theoretical chemistry

Inorganic and organic chemistry

Ionic and superionic materials

Organic solid state physics/devices

Perception

Artificial intelligence

Solid state physics

Cognitive science

Logic and language of computers

Distributed processing software

Low-dimensional structures

Superlattices

Quantum Wells

NEW Semiconductors

Reversible and selective chemical/ physical interactions

Novel transducers

Mathematics

Transphasers

Satellite technology

Optical recording

Optical transmission, storage and processing

Presentation of information - screens, displays

Mobile communications

Database search techniques

Memory-data storage

Information acquisition

NEW MIXTURES OF TYPES OF COMMUNICATIONS

Complex interconnections

More intense communications networks

Signal processing

REDUCING COST AND INCREASING SPEED THROUGH INCREASING BANDWIDTH

man-machine interface

Software engineering

Distributed processing software

Signal conversion technology

Barrier materials

Widening of audio-visual systems

Micro-lithography

Semi-conductor technology

Molecular beaun epitaxy

GREATER VARIETY IN VOICE, TEXT, DATA VIDEO, COMMUNICATIONS

Bioelectronics

Molecular electronics Sensor controll

Internationalisation of commodity and capital markets

Increasing communications based leisure activity

New competition in national businesses and development of international business

Information explosion, wide access to databases

Privacy

Greater/more powerful/complex organisation/personal interactions

More effective use of resources

Increased access to information in a competitive process

Tension between centralised and decentralised Government decision making

Management problems of international business

Internationalisation of languages

6.3. ENERGY

6.3.1. A feature of the world energy scene in recent years has been uncertainty about the future, both in terms of the supply and price of energy. Thus there is an oversupply of energy at the present time and prices are falling but the last decade has seen the cost of energy rise dramatically on two occasions. Uncertainties and price fluctuations are unlikely to disappear altogether in the future and this will have a fundamental bearing on the development of energy technology, which will be carried out partly in response to price changes and partly to ensure supply security in a variety of scenarios for the future. The needs for new technologies will also have a regional or even national character. Countries without indigenous fossil fuels such as France and Japan are investing heavily in nuclear power and other countries are developing appropriate technologies in order to exploit their particular circumstances. For example, New Zealand is looking to convert natural gas to gasoline and chemicals, whereas Brazil is producing ethanol from biomass for transport purposes.

6.3.2 The UK has a relative abundance of all forms of fossil fuels but it is Governments aim to allow world markets to determine their prices. The development of energy technology in Britain therefore mirrors that elsewhere in response to price but with somewhat less emphasis on the strategic need to diversify from oil than in countries less fortunately endowed with fossil energy than is the UK. One clearly discernable trend over the past few years is a move away from expensive liquid fuel for electricity generation and industrial heating. Coal and nuclear power have taken up the electricity generation previously based on oil and it is important to ensure that we are able to continue this trend with an acceptably small environmental impact. Gas heating has almost completely replaced solid fuel in domestic heating and has made large in-roads into the industrial market.

6.3.3. Because of the vital nature of energy to most national economies and the international interdependence of energy supplies, an overview of the world energy situation is maintained by the International Energy Agency. The Agency produces assessments of energy supplies, trends, forecasts, R & D requirements, etc, and in 1982 published a review of "Energy Research, Development and Demonstration in the ICA Countries". The review pointed to the increasing uncertainty of prospects for investment in energy technology, and stressed the inherently long-term nature of energy R & D whose objective was to effect energy balance over decades rather than in the short or medium term. In the short-term, other considerations, political, commercial, industrial, were more important. The IEA policy goals to which most member countries subscribe in guiding energy research are:

a. reduce the level of imported oil, to minimise suppliers potential political leverage over IEA countries economic and security decision-making, and to encourage competitive world oil market behaviour;

b. reduce the outflow of wealth to oil exporters, stabilise energy prices, and control their effects on inflation and recession;

c. encourage development of current technologies to provide increased security of supply, particularly for hydrocarbons, in the near term;

d. assume that long-term promising alternatives to current energy technologies are adequately investigated and available when required.

6.3.4. It is not possible or desirable here to describe the IEA 1982 Review in detail and readers who would like further information should consult the review. In R & D programmes the Agency put a high priority on the substitution of oil by coal, gas and nuclear, including technological means for reducing environmental concerns. In assessing national R & D programmes, the individual technology areas of interest were clearly distinguishable in the following categories

Conservation

Oil and gas
Coal
Conventional nuclear
Advanced Nuclear (Breeder and Fusion Research)
Renewable Energy Sources
Electrical and other sources

In terms of energy policy objectives, energy technologies were grouped as follows:

i. Technologies already available which might address significant impediments to the increased use of the principal substitutes for oil and to greater end-use efficiency;

ii. Promising technologies which in the future could make a major contribution to the energy supply of industrialised countries;

iii. Complementary technologies which promised to provide useful and noticeable additions to the core group of energy resources (ie coal, oil, gas, nuclear, hydro);

iv. Regionally significant technologies, but without widespread impact upon overall energy supply or demand in industrialised countries;

v. Technologies whose applications have specific importance for developing countries, including traditional sources such as fuelwood.

6.3.5. The objectives and priorities of national energy UK R & D policy as outlined in the IEA Review is as follows:

i. to make the best possible use of, and obtain maximum value from North Sea hydrocarbon reserves through optimisation of the period of self-sufficiency in these fuels;

ii. to work towards the more appropriate and efficient use of all fuels;

iii. to develop those sources of energy necessary to meet longer-term requirements ie coal and nuclear power which currently offer the best economic prospects, and to look further into the future at those sources of supply, such as the renewables, whose potential contribution is large but where costs of production need to be brought down and some technical problems solved.

In managing the national R & D programme, a flexible approach has been adopted in which priorities are subjected to continual appraisal in the light of the latest evaluation of national energy supply needs and the relevance of R & D projects to those needs. The IEA commented that it was unclear how specific research priorities were set in relation to overall energy R & D strategy and energy policy formulation. The UK programme is concerned almost solely with securing supplies for the nation at the lowest practicable cost, but such an approach fails to address the large export potential which exists for energy-producing systems, in particular, for less technologically advanced countries without the necessary R & D base to develop their own advanced energy technology. Such considerations apply particularly to renewable energy resources for which large markets exist in countries with climatic conditions that differ markedly from those in the UK.

6.3.6. The average consumption of energy averages about 1000 therms per person each year. Changes in supply of energy in the UK over the decade 1971-1981 are exemplified by the following figures

	1971	1981
Total inland energy consumption by final consumer (therms x 10^9)	57.0	54.9
Total sales of gas (therms x 9)	7.5	16.6

Electricity generated (GWh x 10^3)	236.4	260.4
Total consumption of coal (tonnes x 10^6)	143.6	122.7

(Source: Annual Abstract of Statistics)

The major trend apparent is a slight decrease in total energy consumption with significant changes in the balance of contributors to the total supply. Gas supply and consumption has increased dramatically, with a small rise in the amount of electricity generated and a small decrease in the consumption of coal. A steady increase in energy generation by nuclear techniques has also occurred. A consequential trend, arising from other pressures, at the moment, and one which is likely to continue, is a move away from liquid and gaseous fuels for energy generation and steam raising. In terms of the major consumers of energy, industrial consumption is still the largest but has fallen off in the decade 1971-1981 particularly in the iron and steel industry, and domestic consumption has increased almost to the level of that in industry. Consumption in road and air transport has also risen whilst usage by other smaller sectors has shown minor changes.

6.3.7. The future development of nuclear power is also unpredictable, primarily for social and political reasons although some economic and technological uncertainties remain. Public concern about nuclear power generation, despite its unparalleled safety record and the large numbers of safety assessments which show it to be the safest way to generate electricity, have had and may continue to have an effect on the speed of development of new generating capability using thermal nuclear reactors, but as indicated earlier, the long term trend is for an increase in nuclear power generation. Several major developed countries are carrying out R & D in nuclear technology, partly with a view to export of plant in the coming decades because of the prospect that developing and newly emerging industrial countries will be seeking to increase their manufacturing capability and will require increased electricity supplies. The potential for electricity generation from fast reactors is longer term but the fast reactor does offer large amoûnts of nuclear electricity generation essentialy independently of uranium supply and price.

6.3.8. The promise of energy from nuclear fusion is well beyond 10-20 year scenarios. Nuclear fusion appears to hold the potential to provide large amounts of energy which are practically inexhaustible. Fusion is not, however, completely pollution-free, but it may produce markedly lower quantities of radioactive wastes than fission processes, which are likely also to be generally not so long-lived. The fusion option will, however, require enormous investment and long intervals between decision making and materialisation even if and when the process is shown to be technically feasible. Recently, the large investments in R & D have been questioned and a more collaborative international approach has been suggested. The inherent vulnerability of highly complex energy generating systems may hold hidden problems which might affect both generation and the increasingly highly integrated distribution networks. Such considerations have led some to question whether the major proportion of public funding of R & D on energy supply should be concentrated on technologies concerned with electricity as the means of providing energy to the final consumer.

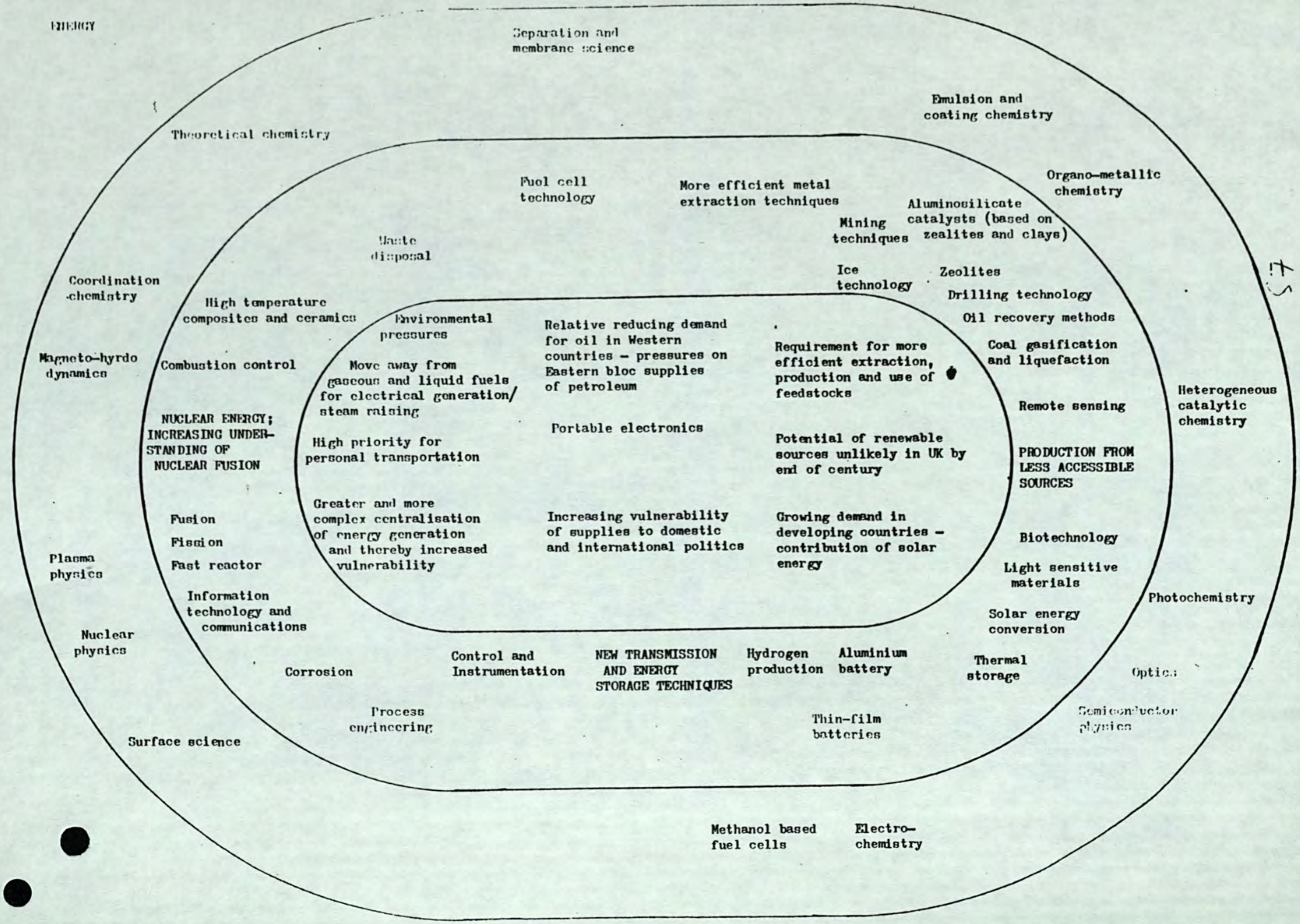
6.3.9 A report by the Process Plant Economic Development Committee of NEDO has suggested that the need to increase the efficiency with which energy is utilised by the process industries will dominate the design of plant to be used by such industries over the next 20 years. Industries where major development in energy efficiency improvement is foreseen are oil, gas, coal and steel. More use will also be made of waste heat recovery. In this context, some 40% of total energy demand by final consumers is in the form of low temperature heat, and technologies are required which reduce the need for or provide such heat more cheaply. Whilst industry has been able to take advantage of processes for recovering waste heat, the opportunities for such exploitation in domestic heating systems are much less.

6.3.10 A number of factors have affected and will continue to affect energy utilisation for transportation. Although car engines have become more efficient in recent years, the use of transportation fuel per person per year is increasing because people are making more and longer journeys. That trend is likely to continue and combined with increasing car ownership resulting from the desire for independent means of travel will increase transportation fuel consumption. Offsetting savings will however be made by improvements in the efficiency of energy utilisation by cars through new design and technology.

6.3.11 Developments in renewable energy technologies are likely to have greater impact in developing than in developed countries although some applications are possible in the UK. Simple passive solar measures can be applied to new houses with economic benefit and the use of waste as fuel is also economic in many situations. Wind and geothermal energy might eventually make a contribution to UK electricity supplies, particularly in special situations, but in the main development of renewable energy technologies will be of greater interest in the context of export of such technologies.

6.3.12 As with transportation, (and most human activities) energy cannot be separated from environmental considerations. We deal generally, with the environment in the next section would emphasise here that development of new energy technology should be linked with appropriate measures, which may require research, to minimise the effects that technology may have on the environment. Such research may be quite cost-effective as an insurance policy. Installation of pollution control technology will probably be more economic at the construction stage than if required to be fitted later. Such technology may, in practice, be exploited with profit, for example, by export. Thus it is recognised that the so-called "Greenhouse Effect", attributed to increase in carbon dioxide in the atmosphere from human activities, will have global impact, and therefore technologies for the control of carbon dioxide emissions will have wide applications. Similar considerations apply to other types of pollution control technology.

ENERGY


Separation and membrane science
Theoretical chemistry
Emulsion and coating chemistry
Organo-metallic chemistry
Coordination chemistry
Magneto-hyrdo dynamics
Heterogeneous catalytic chemistry
Plasma physics
Nuclear physics
Photochemistry
Optics
Semiconductor physics
Surface science
Methanol based fuel cells
Electro-chemistry
Fuel cell technology
More efficient metal extraction techniques
Aluminosilicate catalysts (based on zealites and clays)
Mining techniques
Waste disposal
Ice technology
Zeolites
Drilling technology
Oil recovery methods
High temperature composites and ceramics
Combustion control
Coal gasification and liquefaction
NUCLEAR ENERGY; INCREASING UNDERSTANDING OF NUCLEAR FUSION
Remote sensing
PRODUCTION FROM LESS ACCESSIBLE SOURCES
Fusion
Fission
Fast reactor
Biotechnology
Light sensitive materials
Information technology and communications
Solar energy conversion
Corrosion
Control and Instrumentation
NEW TRANSMISSION AND ENERGY STORAGE TECHNIQUES
Hydrogen production
Aluminium battery
Thermal storage
Process engineering
Thin-film batteries
Environmental pressures
Relative reducing demand for oil in Western countries - pressures on Eastern bloc supplies of petroleum
Move away from gaseous and liquid fuels for electrical generation/steam raising
Requirement for more efficient extraction, production and use of feedstocks
Portable electronics
High priority for personal transportation
Potential of renewable sources unlikely in UK by end of century
Greater and more complex centralisation of energy generation and thereby increased vulnerability
Increasing vulnerability of supplies to domestic and international politics
Growing demand in developing countries - contribution of solar energy

6.4 ENVIRONMENT

6.4.1 The environment has been a growing feature of public consciousness in the recent decade or so, and has played an increasing role in changing social attitudes which have forced economic industrial and social changes affecting people´s perception of standard of living/quality of life and lifestyles. In one sense, the environment is an area where markets for technology in the conventional sense do not exist. Environmental matters are usually the externalisation or consequences of the development of technology. But action taken over real and perceived environmental problems may be the spur to the improvement of technological processes or development of new technologies which have major economic consequences. For example, environmental concerns in the USA over aerosol sprays from cans gave rise to new technologies for fine spraying. Emission control presents considerable opportunity for development of advanced processes and products with wide potential for economic and commercial exploitation both at home and abroad. More recently, international aspects of environmental protection have become a major concern of national Governments and international bodies, stimulated by the realisation that many environmental problems have a trans-frontier and in some cases a global dimension. In the last ten years, action has been taken by the European Community in the form of environment action programmes with the objective of protection and improvement of the environment by the joint activities of Member States.

6.4.2 Many of the more obvious environmental problems of yesteryear in the UK, such as smoke control and river pollution, have almost been overcome by appropriate measures taken some time ago, although some, such as the visual impact of litter, waste, etc still exist, and present concerns about the environment are of a more complex and subtle nature. Although one or two clear problems remain in relation to pollution, recent environmental considerations concern a wide range of interrelated issues of relevance to conservation, economic development, resources, pollution, life-styles, etc, the scientific basis of which is complex and often little understood. Recent environmental thinking has been concerned more with the total concept of a more sustainable form of society, and with the notion that scientific advance should have some regard for environmental considerations as an insurance policy whose object is to ensure that the base upon which future productivity is to be founded is not permanently damaged. We do not intend to discuss here the complete range of current environmental concerns, these are considered in the 10th Report of the Royal Commission on Environmental Pollution, but draw attention to one or two major issues which will be of relevance to the development of technology in the future.

6.4.3 There is little doubt that public concern about environmental issues will increase in the next 10-20 years in the United Kingdom, rather than diminish. Scientific and technological issues are involved and require long term fundamental studies, which must be started before public concern escalates too far, and also in order to pre-empt the need for expensive solutions or misguided treatments for environmental problems. We consider that the following issues together with the relevant areas of study are likely to become a focus of public pressure and need greater attention in research at the expense of some of areas of environment research currently supported by public funds:

acid rain : lakes/soil

ozone : trees
human health

nitrites : health
nitrates : health of the very young

diesel/petrol : carcinogens
mutagens

CO2 : greenhouse effect

disposal of nuclear waste : basic science, geology

infrastructure problems

eg. lead piping : technology
sewage disposal : bacteria in sea

sewer deterioration : fault-finding technology

marine pollution : audit needed eg. mercury etc

replacement for animal experimentation : fundamental biological and medical science

6.4.4 The whole question of exhaust emissions will be vital to vehicle manufacture technology in the next decade. Various techniques to reduce pollution from car exhausts are available, some of which are more costly than others but the technology requires further development to provide environmentally and economically acceptable solutions. Consideration of exhaust emission technology should also include emissions from vehicles powered by diesel engines because of the possible hazard from carcinogens and photochemical smog from industrial or other sources.

6.4.5 One of the most pressing environmental problems at the present time is that of acidic depositions. A considerable body of information is building up on the nature of such depositions, and the main principle involved appears to relate to the conversion of gaseous emissions from industrial and urban sources, particularly sulphur dioxide (SO2) and nitrogen oxides (NOx) to acids in the atmosphere. The international consensus appears to be that, in the long term, the only effective actions which can be taken is to control the emission of gases which lead to acid deposition. The major source of such gases is the combustion of fossil fuels, and power stations have been identified as one major source of acid deposition. The Royal Commission on Environmental Pollution in its tenth report considered that acid deposition was "one of the most important pollution issues of the present time". It was recommended that high priority should be given to research into the cause and effects of acid deposition, the interaction with other environmental pollutants, and to remedial action. A basic understanding of the mechanisms which produce acid deposition was lacking, which prompted the Royal Commission not to make any recommendations about measures to provide control. Research into emissions of whatever type and their effect could have far-reaching and important economic consequences in the long-term. Such research is not easily undertaken by private industry and is more suitable for the broader and more collaborative approach of publicly funded R & D programmes. But the public institutions concerned have been slow to react to such problems and have tended to concentrate on the natural ecological habitat often in countries and areas which have little relevance to UK conditions rather than the environment in the UK as affected or potentially affected by man.

6.4.6 Concerns have also surfaced recently particularly with respect to the safety aspects of the chemical and pharmaceutical industries, and to the transport of hazardous materials, which seem likely to attract increasing attention. Safety-related technologies in these fields may be an area of considerable promise.

6.4.7 Better information on weather in the short-term could have potential economic significance, for example, for farming, water resources, environmental and disaster management, etc. In the longer term, we draw attention to climatic change and the so-called "green-house effect". Information is increasing about the cyclical warming and cooling of the planet, and it has been suggested that the present interglacial warm period may be about to end. Glacial periods have been related to levels of carbon dioxide trapped in ice during such periods, the implication being that atmospheric carbon dioxide is lower during ice ages. It has been speculated that the carbon dioxide produced by human activity may therefore have beneficial effects in terms of the "green-house" effect. More information is required about this and other climate/weather effects to be of potential economic use.

6.4.8 Scrutiny has been maintained in recent years on the levels of ozone in the atmosphere, after the finding in the 1970s that ozone in the upper atmosphere might suffer destruction from the effects of man-made pollution, particularly chlorofluorocarbons used as aerosol propellants. The ozone layer in the atmosphere acts as a natural filter of UV radiation thereby preventing damage to health from excessive exposure to such radiation. The urgency of concerns about ozone in upper atmosphere has diminished recently but new problems have arisen about ozone levels at or near the earth's surface. The production of photochemical pollution by the action of sunlight on combustion products, mainly nitrogen oxides and hydrocarbons, from the burning of fossil fuels yields a mixture of photochemically produced gases of which ozone is a primary component. In particular weather conditions, concentrations of atmospheric ozone near the ground may reach levels which are toxic to sensitive indicator plants. Excess ozone in the air may also have physical effects on humans. Further research is required to obtain a better understanding of the environmental, physical and consequential economic effects of ozone and other compounds produced by photochemical reactions in the air.

6.4.9 Disposal of radioactive and other toxic forms of waste may have economic implications for the future. Some short term solutions for dumping waste have been unsuccessful in the USA and have led to considerable economic penalties. In the next two decades, many countries will be required to consider the long term storage of radioactive waste and spent fuel from nuclear plants; practical technologies will be required after that time. A key factor will be the location and economic utilisation of sites where toxic and radioactive wastes can be disposed of acceptably. Considerations of technology for nuclear waste disposal should also include the transport of nuclear materials and spent fuels.

6.4.10 At the scientific level, the impact of intensive farming on the environment is little understood. For example, nitrates and nitrites are of health concern but information on how nitrates enter ground water is lacking. Of the nitrate added to the soil as fertiliser, some 60% is taken up by plants, about 20% goes into the atmosphere, and the rest finds its way into ground water. Phosphates are also put on to the land as fertiliser, but phosphate is bound to the soil and levels are gradually building up; the long-term effect appear not to have been considered. Research in agriculture in the past has tended not to provide the farmer with reasonable alternatives to increasing agricultural intensification. But agricultural research is presently at a crossroads and the opportunity should be taken to seek new directions and a broader approach in R & D in order to take account of the wider perspectives of land use and exploitation in farming. Perceptions in the planning of research in agriculture should have greater regard for "concerned" systems of agricultural production.

6.4.11 Agriculture has come under close scrutiny recently in relation to the effects of increasing agricultural intensification on the landscape, conservation of wildlife, farm waste pollution, straw burning, access to open space and the countryside, and health and welfare of farm livestock. Conservation pressure groups are seeking research into the financing and accounting in agriculture and would wish to see any enquiries set in a European context in order to develop the best fiscal policies for the future development of agriculture and the marketing of agricultural products. It seems likely that pressure will increase to tackle problems like straw-burning and ploughing up of uncultivated land. We discuss science and technology in agriculture later but note that the whole thrust of conservation bodies is to increase the acceptability of an efficient agriculture.

6.4.12 Availability, location, and access to resources has become an important environmental issue in recent years. Such concerns stem from the early 1970's and the publication of books like "Limits to Growth", but recent thinking about resources has been more detailed and searching. The increasing need to obtain resources from remoter and more hostile environments, has placed greater emphasis on the development of more sophisticated technology. Detection, location, economic extraction and exploitation technologies, are of increasing importance. Interest in resources located, for example, in deep oceans, polar regions, high mountains, will increase. Attention will also be given to economic transport of resources over great distances of hostile environments which will require consideration of environmental effects.

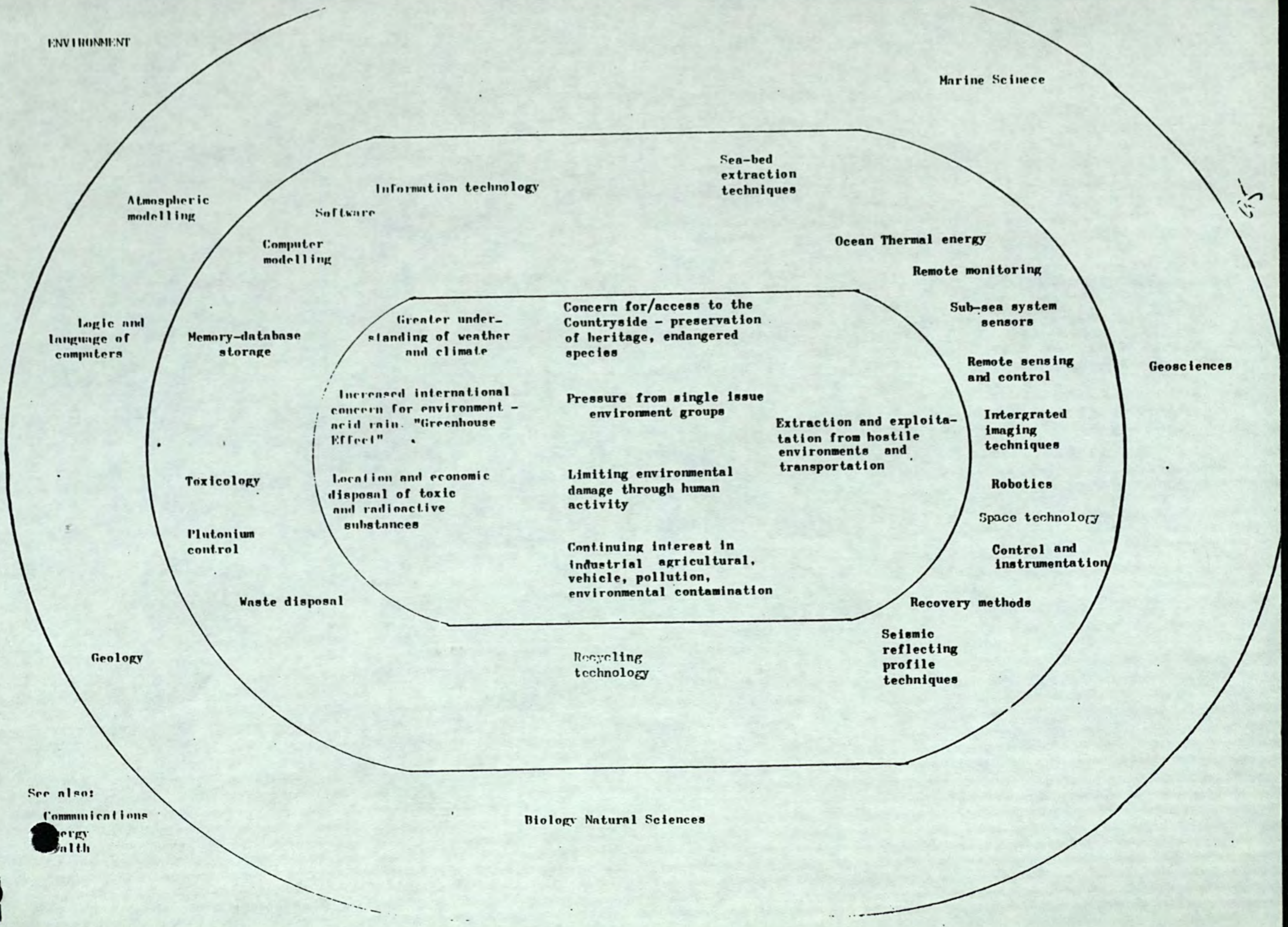
6.4.13 Public awareness of environmental problems and the number of environmental pressure groups have increased in recent years. In many countries "the environment" has become a political issue. Such pressure has produced a response from Governments, for example, in the USA by the continued interventionist activity of the Environmental Protection Agency, and by the development of environment action programmes by the European Community. The public interest has been stimulated by "pressure groups" whose interpretation of data is not always impartial, nevertheless, as the Tenth Report of the Royal Commission on Environmental Pollution pointed out, there is "much evidence of a growing professionalism in many voluntary organisations in the environmental field, and with it an ability to evaluate and present technical and scientific reports which compare favourably with those of officially sponsored researchers".

6.4.14 The environment is increasingly being considered in the wider social, economic, political and technological context, for example, the interactions with the energy, agriculture, and transportation industries are of particular importance. Most sectors of UK industry have recognised the importance of environmental factors in their activities. Recently the CBI concluded that awareness of environmental pressures "could uncover possibilities hitherto not recognised as beneficial". Competitive opportunities may arise from environmental constraints on industrial activities, and opportunities in technological innovation stimulated by recognition of environmental standards as an element of the market. Another aspect of such an approach, is that pollution control may be regarded as an "insurance policy", against problems which could significantlyly affect the future competitive position of the country. Incorporation of pollution control equipment at the plant construction stage is invariably more economic than if such equipment has to be installed later. Thus technology, innovation and industrial development should advance with environmental policy, in order to anticipate problems and develop timely solutions. Such an approach has been adopted as national policy in some countries notably West Germany and the Netherlands.

6.5 TRANSPORTATION

6.5.1. The last twenty years or so has seen a decline in travel by public transportation systems and an enormous increase in travel by private

ENVIRONMENT



Marine Scinece

Atmospheric modelling

Logic and language of computers

Geology

Geosciences

Biology Natural Sciences

Information technology

Software

Computer modelling

Memory-database storage

Toxicology

Plutonium control

Waste disposal

Recycling technology

Sea-bed extraction techniques

Ocean Thermal energy

Remote monitoring

Sub-sea system sensors

Remote sensing and control

Intergrated imaging techniques

Robotics

Space technology

Control and instrumentation

Recovery methods

Seismic reflecting profile techniques

Greater understanding of weather and climate

Increased international concern for environment - acid rain. "Greenhouse Effect"

Location and economic disposal of toxic and radioactive substances

Concern for/access to the Countryside - preservation of heritage, endangered species

Pressure from single issue environment groups

Limiting environmental damage through human activity

Continuing interest in industrial agricultural, vehicle, pollution, environmental contamination

Extraction and exploitation from hostile environments and transportation

See also:

Communications
ergy
alth

road vehicles as indicated by the following figures:

Passenger Transport (Billion passenger kilometres)

	1961	1983
Air (Domestic)	1.0	2.8
Rail	39	35
Road		
Public service vehicle	67	42
Private transport	136	414
Bicyles	10	5

(Source: Social Trends 15, 1985)

However, vehicle ownership in the UK lags behind that in some other countries; for example, the number of passenger vehicles for every 1000 of population in the UK in 1982 was about 290 compared with roughly 540 in the United States, and some 360-380 in France and West Germany. Surprisingly, Japan at 209 vehicles per 1000 of population, in 1981, has a lower rate of car ownership than these other countries.

6.5.2. A fall-off in bus services has been the most marked trend in the two decades up to 1982 but a proportion of the population, for varying reasons, in both urban and rural areas are dependent on public service transport. A number of experiments have been carried out to improve bus services such as `post bus´ services, express and limited stop buses, and `park ride´ bus services. Undoubtedly further innovation in bus type and bus services will be tried but whether this will have a major impact on private transport remains to be seen.

6.5.3. Increase in private vehicle ownership has increased as a result of increased demand for the convenience of private transport and ability to supply. Other factors, such as the subsidised company car, have also played a part; a car-based lifestyle has become firmly established. Increased car ownership has resulted, for example, in more dispersed low density housing, the tendency for greater concentration of the service sector, shops, schools, medical facilities, rendering them relatively less accessible.

6.5.4. Whether the dynamic expansion of car ownership will continue in the next decade remains to be seen. In the UK, the market does not appear to be completely saturated, practically all households in the higher socio-economic groups own one car or more, but ownership in lower income households is much less. The tendency in the developed world however is for global saturation in the car industry and Japan, for example, which is now the world's leading car-maker, no longer sees the car industry as a growth area. In the USA, the market is already moving towards a replacement market but the size of that market may be insufficient to provide the continued growth in the car industry witnessed in the last two decades. The export market to the developing world may not provide a substitute since such countries are rapidly expanding their own car industries.

6.5.5. The most significant trend in the car industry in recent years has been the increasing internationalisation of design and manufacture, as production sharing on a world basis is becoming established in many industrial sectors. Certain future trends in car innovation have been suggested as follows:

- lighter, smaller, more energy efficient cars
- aerodynamics and components efficiency
- new materials in design and engines
- sophisticated electronics and computers
- gas turbines in buses and heavy goods vehicles
- manufacturing technology including robotics
- lightweight diesel engines for cars

However, against the trend for increasing internationalisation is an apparent increased demand in domestic markets for individual distinctive features in cars, which is providing scope for small and medium sized national manufacturers. Such divergence in the market could be encouraged by technological advance.

6.5.6. It has been estimated that more fuel is wasted by drivers taking the wrong or least optimum route than by any other form of fuel wastage, such as that from traffic queues, engine inefficiency, etc. A major area of interest, therefore, in developments related to motor vehicles is in electronically based "intelligent" route-finders in cars and automated highways; the latter would also have important implications for road safety. In this respect, increased sophistication of electronic equipment in cars could have a major impact, for example, by voice activation of certain control devices and audio warning of hazards or in-car conditions.

6.5.7. A major pressure on technology in the next two decades will be the drive to reduce pollution from vehicle emissions. Europe lags behind the USA and Japan in terms of environmental considerations relating to exhaust emissions, but the European Commisson is actively examining the courses available to reduce lead in petrol. Different technological options are available which will no doubt influence vehicle technology in the future.

6.5.8. Between 1972 and 1982, the number of passengers carried in aircraft flights between the United Kingdom and abroad increased by 56%. The total number of passenger movements through terminals at United Kingdom airports in 1983 was about 61 million. Of this total, some 28m resulted from international scheduled services, 18 million from international charter services, and about 15 million from domestic services. An analysis by the International Passenger Survey, showed the following proportions of international traffic at major UK airports in 1983.

Traffic Category	UK residents %	Foreign residents %
<u>Scheduled</u>		
Business	17	21
Leisure	26	36
Total	43	57

Charter		
Business	2	1
Leisure	82	15
Total	84	16

The largest market to and from the UK in 1983 was Spain with 9.6 million air passengers, followed by the USA (5.8 million), France (3.3 million), Germany (3.2 million), Italy (2.5 million), Greece (2.0 million), Netherlands (1.8 million), Switzerland (1.7 million), Eire (1.6 million), Canada (1.4 million), and Portugal (1.1 million). These countries accounted for 70% of the total UK international market.

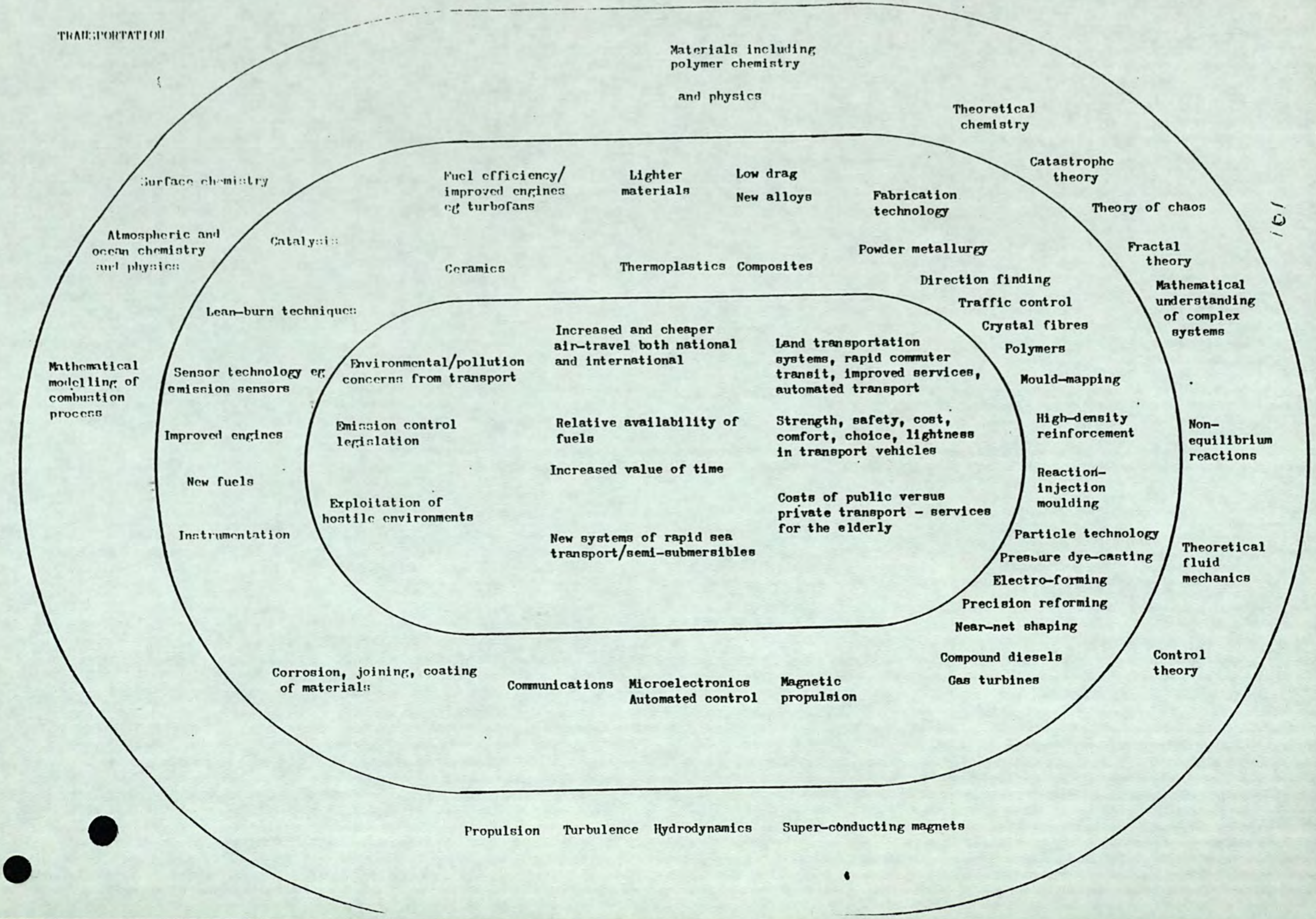
6.5.9. In the USA, domestic air travel increased spectacularly following deregulation of the industry, as a result of pressures to decentralise power away from the major carriers, and in recent years regional airlines have shown greater growth and profits than the large national airlines. The impetus to growth in domestic transport internally and within Europe may come from technological development related to noise, fuel, efficiency, size etc in air transport associated with a reduction in the cost of such travel. Recent years have also witnessed an increase in light aircraft numbers for reasons of business and pleasure. Such a trend may continue although individual air transportation systems for everyone, predicted by some, is not considered to be realistic.

6.5.10. So far as mass public transport systems are concerned, although a downward trend has been apparent in recent decades, the future is uncertain. An aging population may increase the requirement for more and cheaper public transport. Improvement in the services provided by technology of such systems may attract particular sections of the population away from personal road transportation. For example automated and rapid transit systems may be more attractive to commuters.

6.5.11. Trends in sea transport are even more unpredictable. The major phenomenon of sea transportation in the last two decades, namely containerisation, appears to be reaching the limit of development. Diversity in shipping requirements has been growing, whether to supply off-shore industries, low temperature cargos, special materials, and no doubt further opportunities will present themselves in the future. Exploitation of the sea-bed may also be a spur to ship development. Energy costs of conventional vessels have stimulated the search for more efficient ways of ship propulsion.

6.5.12. Over the last few decades, there has been a continual decline in sea passenger transport and such markets are now confined to speciality areas such as for cruise or leisure purposes. At the same time, major shipbuilding enterprises have developed in the Far East which have taken a large share of the shipbuilding market from countries like the UK which have been traditionally involved in building ships. However, with the rationalisation of the UK industry and adoption of the techniques of production and civil engineering techniques opportunities for the industry have improved. Computer-aided ship design has been widely adopted in British shipyards but there is no centre for operational simulation in the UK at a time when this will become an integral part of the design process for merchant ships and marine vessels. In the medium term, areas with potential lie in improved design criteria for ships with low noise signature or unconventional hull forms. Recent increases in fuel costs have generated interest in alternative forms of propulsion. Unconventional designs making use of wind or wave assistance are possible, and in the longer term it is conceivable that nuclear driven steam turbines may be used in merchant ships. Other opportunities exist in ship automation, ship control, and advanced communications making feasible highly automated and ultra-low manned ships. The exploitation of resources from ice-covered regions in the future will require development of technologies upon which to base production facilities, special carriers, supply vessels and the total operation in various sea/ice environments.

TRANSPORTATION



Environmental/pollution concerns from transport

Emission control legislation

Exploitation of hostile environments

Increased and cheaper air-travel both national and international

Relative availability of fuels

Increased value of time

New systems of rapid sea transport/semi-submersibles

Land transportation systems, rapid commuter transit, improved services, automated transport

Strength, safety, cost, comfort, choice, lightness in transport vehicles

Costs of public versus private transport - services for the elderly

Fuel efficiency/ improved engines eg turbofans

Lighter materials

Low drag

New alloys

Fabrication technology

Catalysis

Ceramics

Thermoplastics

Composites

Powder metallurgy

Lean-burn techniques

Sensor technology eg emission sensors

Improved engines

New fuels

Instrumentation

Direction finding

Traffic control

Crystal fibres

Polymers

Mould-mapping

High-density reinforcement

Reaction-injection moulding

Particle technology

Pressure dye-casting

Electro-forming

Precision reforming

Near-net shaping

Compound diesels

Gas turbines

Corrosion, joining, coating of materials

Communications

Microelectronics Automated control

Magnetic propulsion

Materials including polymer chemistry

and physics

Theoretical chemistry

Catastrophe theory

Theory of chaos

Fractal theory

Mathematical understanding of complex systems

Non-equilibrium reactions

Theoretical fluid mechanics

Control theory

Surface chemistry

Atmospheric and ocean chemistry and physics

Mathematical modelling of combustion process

Propulsion

Turbulence

Hydrodynamics

Super-conducting magnets

6.6. HEALTH

6.6.1. In 1981, circulatory disease was responsible for more than half the total number of deaths in the United Kingdom, and the next most significant cause of mortality was cancer; the latter disease was also responsible for more deaths in women than in men. Among younger people, in the age range 5-35, the effects of accidents or violence was responsible for more deaths than was disease. Perhaps the major achievement in the health care field in recent decades has been the conquest of many infectious diseases. The reason for this improvement is due almost entirely to the effects of preventive medicine programmes particularly those concerned with vaccination of the very young. The benefits of some preventive medicine programmes have yet to be realised; cervical cytology screening has been carried out for a number of years now but deaths from cervical cancer have been little affected. In this case and for some vaccines, further technological development is clearly required.

6.6.2. Other health trends show an increase in new patients with mental illness or handicap, a decrease in the number and length of stay of mental in-patients in hospitals, and an increase in out-patient numbers. Perinatal and infant mortality have declined steadily over the last two decades and there has been a gradual increase in the number of prescriptions dispensed. Deaths from accidents on the roads, railways, at home, and at work have all decreased in the last twenty years. Drug addiction and the incidence of sexually transmitted diseases have both increased in the last decade. In the last five years, the habit of cigarette smoking has declined.

6.6.3. The ageing of the UK population which has been referred to earlier is reflected in the increased demand for residential homes for the elderly; although more of such accommodation is provided by local authorities, voluntary and private homes have shown the greatest increase in recent years. The trend towards community care and sheltered housing is likely to continue. The increasing age of the population has considerable implications for resources as the following figures show:

NHS annual costs per person in 1982
in Great Britain

Age	£ per person	
	Male	Female
Under 1	491	401
16-24	119	115
25-44	131	136
45-64	201	191
65-74	423	386
75 or over	803	984

(Source: Social Trends 15, 1985)

Such figures provide considerable incentive to determine and apply suitable measures to reduce ill-health in the elderly.

6.6.4. A consequence of people remaining physically active for longer, is an increase in the number of elderly with diminished mental activity and this could present serious social and institutional problems. [It has been suggested that some 15% of the population will be affected by pre-senile dementia]; the elderly also suffer a decrease in learning and memory faculties. Such a problem presents a challenge to technology and continuing research in the field of neuroscience holds the promise of treating such conditions by drug therapy. Medical progress has achieved considerable success, so far, in increasing the life expectancy of people, and some success in terms of vision, mobility, with respect to improving physical fitness towards the end of life expectancy. But medical advances will be particularly important in future in maintaining mental capacities so that elderly people can live a full and interested life for longer.

6.6.5. Awareness of health and fitness has been sharpened in recent years, which has been reflected in general concern about the diet, healthy eating, and physical fitness. Among the younger sections of the population such concerns have shadowed the trend in the USA toward less reliance on the medical establishment and more reliance on self-care and a holistic approach to bodily health. In the USA, as a result of the self-care phenomenon the development and sales of equipment for self- diagnosis and monitoring has mushroomed. Small medical electronics companies are supplying much more equipment to the general public than to the medical profession. A spur to such developments has been costs, or more precisely the economics of a self-care approach compared to treatment in hospital. Central to the US self-help concept is the redefinition of health from a mere absence of disease to the existence of a positive state of wellbeing. Medical technology and health care is a strong growth industry in the USA.

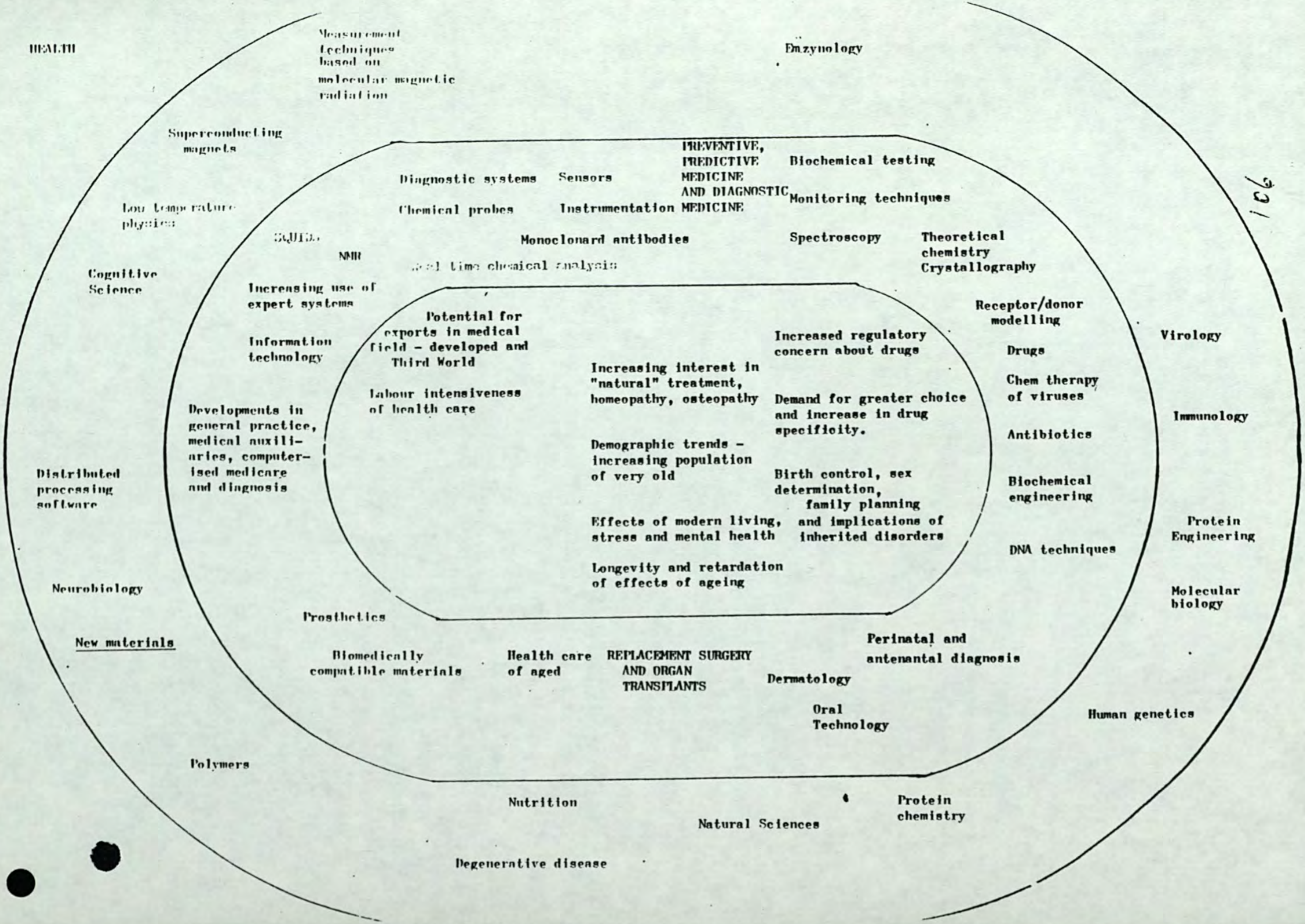
6.6.6. The burden of premature death in the UK from circulatory disease presents a considerable challenge to the pharmacological approach. Drugs companies have placed increasing R & D resources with some success in the search for suitable therapeutic compounds for treatment of circulatory conditions. However the number of new drugs generally reaching the market has declined in recent years as companies have placed more resources in understanding the basis of disease processes and in sophisticated research techniques. Increasingly regulatory proliferation has also slowed the development of new drugs. Whether action relating to recent concerns about the use of animals for drugs testing will be a further inhibitory factor in the future remains to be seen.

6.6.7. In recent years, there has been increasing demand for ways to assist in overcoming the problems of low or lack of fertility in both women and men; coupled with this demand has been a desire to determine prenatally whether any imperfection might be present. New technologies like <u>in vitro</u> fertilisation, ovulation stimulation, embryo transplantation, etc have been developed in response to the former demands and prenatal diagnosis, gene screening, etc to the latter. Experiments, under appropriate control, in this area are likely to continue with a view to the much closer monitoring and manipulation of the processes of creation to the benefit of parents and offspring alike. Developments in the control of contraception seem likely to lead to improved safety for women over thirty years of age and methods applicable to male contraception.

6.6.8. Research into genetically determined diseases will have wide implications for medical treatment. Pre-natal diagnostic techniques are advancing rapidly, for example, using ultra-sound techniques it is now possible to determine the state of organisation of the foetus at 6 weeks of age. It has been shown recently that foetal cells are present in the maternal blood circulation and this might present opportunities to examine genetic make up of the foetus at an early stage of pregnancy. Body chemistry is determined by genetic make up and although only a small percentage of the population suffer from serious genetic defects, larger numbers are affected by chromosonal defects. By determining the genetic basis of disorder at a molecular level, control might be approached through genetic engineering. In the longer term, conditions which predisposed to disease but which were not necessarily lethal might be treated in this fashion.

6.6.9. It is clear that information technology will have a major impact in the medical field, and medical practitioners will increasingly be assisted by computer systems which can store and manipulate the knowledge of human experts. Such developments will be speeded by the increasing computer literacy of students undertaking medical training and the steady infiltration of computer technology into the major medical areas and practice. Thus, systems are becoming available already which afford doctors the facility to obtain a variety of initial diagnoses, with suggestions as to which one is the most likely, by entering a patient's medical record into a computer based diagnostic system, containing the appropriate knowledge base and database. The coupling of advanced electronic and medical instrumentation with IT systems in hospitals will have far-reaching consequences for surgical treatment and hospital practice. We are already seeing pilot experiments in the UK National Health Service with the first film-less hospital.

HEALTH



Measurement techniques based on molecular magnetic radiation

Enzynology

Superconducting magnets

Low temperature physics

Cognitive Science

Distributed processing software

Neurobiology

New materials

Polymers

Nutrition

Degenerative disease

Natural Sciences

Protein chemistry

Human genetics

Molecular biology

Protein Engineering

Immunology

Virology

Diagnostic systems

Sensors

PREVENTIVE, PREDICTIVE MEDICINE AND DIAGNOSTIC MEDICINE

Biochemical testing

Chemical probes

Instrumentation

Monitoring techniques

SQUIDS

NMR

Monoclonard antibodies

Spectroscopy

Theoretical chemistry
Crystallography

Real time chemical analysis

Increasing use of expert systems

Information technology

Developments in general practice, medical auxiliaries, computerised medicare and diagnosis

Receptor/donor modelling

Drugs

Chem therapy of viruses

Antibiotics

Biochemical engineering

DNA techniques

Prosthetics

Biomedically compatible materials

Health care of aged

REPLACEMENT SURGERY AND ORGAN TRANSPLANTS

Dermatology

Oral Technology

Perinatal and antenantal diagnosis

Potential for exports in medical field - developed and Third World

Labour intensiveness of health care

Increasing interest in "natural" treatment, homeopathy, osteopathy

Demographic trends - increasing population of very old

Effects of modern living, stress and mental health

Longevity and retardation of effects of ageing

Increased regulatory concern about drugs

Demand for greater choice and increase in drug specificity.

Birth control, sex determination, family planning and implications of inherited disorders

6.7. HOUSING AND BUILDING IN THE UK

6.7.1. A number of clear trends in housing and building over recent decades are apparent. One major change has been in the public and private sector shares of construction, reflecting an increase in privately built housing at the expense of construction by local authorities. During the last two decades, there has been a steady increase in the number of dwellings over the number of households, and the surplus of dwellings which has accumulated is largely comprised of second homes and unfit housing, although much of the latter is, however, occupied. What is also apparent, as shown by the following figures, is the increasing diversification of housing types.

Age of building	Detached House	Semi-detached House	Terraced House	Purpose built flat or maisonette	Converted flat or maisonette rooms
Pre 1919	15	13	50	6	15
1919-1944	13	46	29	9	3
Post 1964	26	23	24	26	1
All households (present)	17	31	32	14	5

(Source: Social Trends 14, 1983)

Thus the age of the terraced house in the early part of the century, gave way to the semi-detached house in the 1930's to be replaced recently by building of detached houses and flats/maisonettes. An important trend in the last two decades has been the increasing amount of household living space; the average size of household decreased from 3.09 persons in 1961 to 2.64 psons in 1982. The reasons for this have been the increased in one person households from 12% in 1961 to 23% in 1982, the fall in birth-rate from the mid-1960s, and the decrease in the number of large households ie a trend to smaller families.

6.7.2. Since 1951 owner-occupation has about doubled from 30% to 59% of all dwellings. Renting from local authorities has increased at the expense of renting privately but in recent years renting from local authorities has declined as more local authority housing has been sold to the tenants. Renting of accommodation is greater among the elderly population and for divorced or separated women.

6.7.3. So far as consumer durables in households are concerned, the market for some "white" goods such as refrigerators and other goods like vacuum cleaners is almost saturated and the market for others, for example, colour televisions, washing machines, telephones, is rapidly becoming filled. The major opportunities for these products relate therefore to innovation in technology in order to encourage replacement and second purchasing. Some 60% of households now contain domestic central heating. For other household durables such as deep freezers, tumble-driers and dishwashers there is still a considerable market to be satisfied. Official statistics are not available on electronic equipment in the home.

6.7.4. The potential for further penetration of electronic equipment and electronically controlled equipment into households is considerable. Thus there is considerable scope for improving the services provided by and ease of use of present equipment whether concerned with cooking, housework, entertainment, etc and for the development of markets in new electronically controlled labour-saving devices and increasing the variety of equipment in the home. A number of scenarios have been predicted for the interconnection and central control of household equipment, and for communications systems with households from external sources. Opportunities for technology ar many and varied; much of the technology is already available, and only the slowness in removal of constraints has prevented more rapid exploitation of opportunities. Such constraints relate to improvements in housing stock, change in family size and age, development of standards and regulatory frameworks, perceptions by consumers of cost/benefit and in the case of communications development of physical networks. The concept of an interactive home system which controls the functions of entertainment, appliances, environment, energy balance, learning, metering, security, information, and communications in the home, has been developed which has implications for industries concerned with brown goods, white goods, home computing, monitoring, metering, telecommunicatios and construction. Such developments will also have consequences for business planning because of the increasing complexity and interaction of consumer electronics sectors in which companies will increasingly need to orientate analysis and opportunities of exploitation to markets requiring cross-product strategies and a presence in several market sectors. The Electronics Consumer Goods Economic Development Committee has concluded that "the struggle for supremacy in IT-based industry will centre in the domestic environment and not commercial", and that the consumer electronics industry in the UK had been badly over-looked in the past.

6.7.5. Architectural styles and approaches over the decades have tended to be conservative and rarely imaginative in the private housing sector; architecture for public buildings has tended to be more innovative. With a greater variety of demand for housing and changing lifestyles, it is possible that a richer more varied architecture will be demanded in the future. In the USA, architecture is going through a period of dramatic change, with a high degree of experimentation taking place in terms of design, materials, technology. However, such innovation and advance in the UK is largely prevented by restrictive building regulations, and the conditions relating to the financing of house or building purchase.

6.7.6. In real terms, the costs of building and maintenance has increased in recent years. Also, an increasing proportion of unfit housing and housing in serious disrepair is being concentrated in the owner-occupied sector. Those trends have contributed to the growth of the DIY industry in spite of a reduction in support fron central and local government for renovation. With the reduction in the rate of reconstruction of new housing and of demolition for slum clearance, that trend would seem set to continue. Disillusionment with increasing maintenance costs could lead to increased demands for better quality whic would have major implications for the industry in terms of approaches to and materials for building.

6.7.7. The change in type of dwelling construction referred to earlier has increased the amount of living space available to people. Housing construction is also related to other factors such as the availability of work, ease of travel to work, accessibility to services, shopping, community activities, etc. In the future information technology will play a role in where people choose to live, and may produce even more dispersed housing demands.

6.7.8. A recent Jordan Survey of the building industry showed that it is dependent on a diverse range of products and materials from metal, chemical and timber products to ceramic, bulk material, electrical equipment. The activity of the building materials industry is largely concerned with the conversion of basic and dispersed materials into manufactured goods for use almost entirely in building and construction. Such materials are characterised by their high bulk/low value ratio making them costly to transport and therefore confined in their sales area. The following figures show the production trends of some major building materials in recent years.

	Production		
	1969	1974	1979
Cement (1000 tonnes)	17460	17781	16140
Bricks (millions)	6734	5575	4866
Roofing tiles (1000 sq metres)	25867	27359	28263

Plasterboard (1000 sq metres)	82824	110861	113961

(Source: Housing and Construction Statistics 1980)

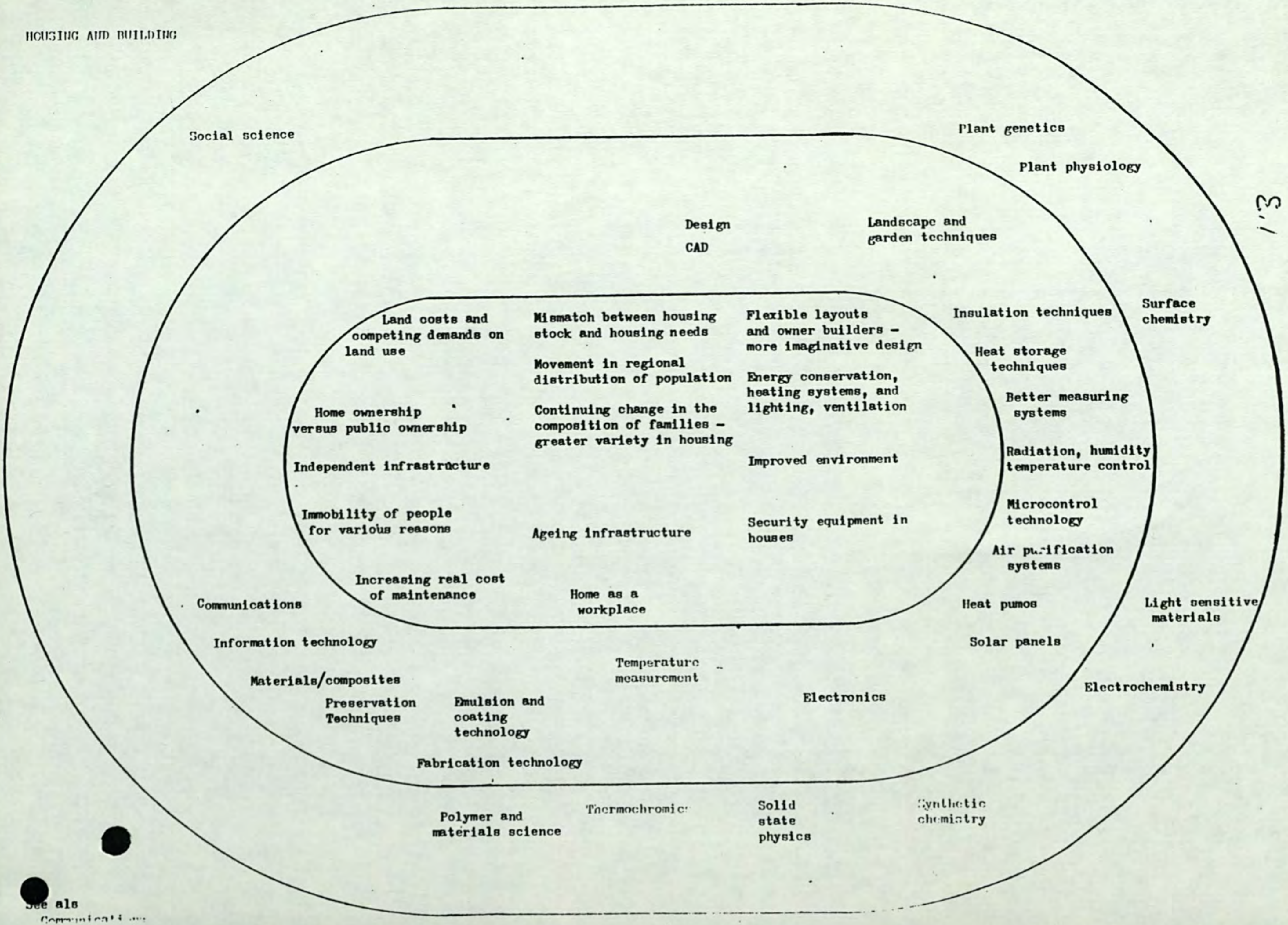
The downward trend in production of cement and bricks over the decade 1969-79 reflects the gradual decline in construction during that period. Increases in production of roofing tiles and plasterboard has resulted from increased activity in the refurbishment and renovation of property. One sector of the construction industry which has increased production is that concerned with the building of new commercial property.

6.7.9. The decline in production in some major building industry sectors has produced a response in terms of increased specialisation and diversificatn in products, such as different types of decorative brick, ceramic tiles, plastic building materials, etc. It has also provoked new technology in the effort to open up new markets for construction materials for example faced chipboards, new mastics and adhesives, central heating and pumping equipment, insulation materials, double-glazing as awareness of energy costs has increased. Fashion has also played a role with the development of the concept of "fixed" furnishings particularly in units for kitchens, and pine became a dominant feature of furniture fashions. Large companies in the building materials sector also diversified into the growing do-it-yourself field and the hight street hardware shop declined in the face of competition from the very large DIY stores. Another aspect of the diversification and specialisation in building materials, has been the increase in specialist trades and skills in the construction industry.

6.7.10. The growth area for the building industry in the last decade has been in renovation and improvement of existing property. Such activities have been confined mainly to the private housing sector and commercial sector; considerable potential still exists for further such activities in the housing sector but greater scope exists probably in the private industrial sector. Some 50% of the housing stock is over 50 years old and much of the factory infrastructure is old. Development of new industrial processes and improved technology in materials handling, should present major opportunities in the market for redevelopment and renovation of deteriorating, inefficient industrial property. New production processes and technological innovation in building materials should lower the cost of production, and provide technically improved materials requiring development of specialist trades to exploit them. In order to offset the decline in markets for traditional building materials, new products should be developed and consideration given to new demands arising from increased affluence and leisure for products and processes hitherto generally unavailable.

6.7.11. In the building sector, technical change has not been encouraged by the regulatory framework within which it operates. Such regulatios have acted as a disincentive to the development of new materials and new concepts, particularly, in domestic house building. A regulatory change to provide incentives for a more scientifically quality controlled approach to construction would release significant opportunities for the construction industry. Further opportunities for a more imaginative and innovative approach in construction would also be facilitated by relaxing of requirements by those concerned with provision of finance for housing construction and purchase of housing.

HOUSING AND BUILDING



Land costs and competing demands on land use

Mismatch between housing stock and housing needs

Flexible layouts and owner builders - more imaginative design

Movement in regional distribution of population

Energy conservation, heating systems, and lighting, ventilation

Home ownership versus public ownership

Continuing change in the composition of families - greater variety in housing

Independent infrastructure

Improved environment

Immobility of people for various reasons

Ageing infrastructure

Security equipment in houses

Increasing real cost of maintenance

Home as a workplace

Design

CAD

Landscape and garden techniques

Insulation techniques

Heat storage techniques

Better measuring systems

Radiation, humidity temperature control

Microcontrol technology

Air purification systems

Communications

Heat pumps

Information technology

Solar panels

Temperature measurement

Materials/composites

Preservation Techniques

Emulsion and coating technology

Electronics

Fabrication technology

Social science

Plant genetics

Plant physiology

Surface chemistry

Light sensitive materials

Electrochemistry

Polymer and materials science

Thermochromics

Solid state physics

Synthetic chemistry

See als
Communications

6.8 FOOD AND CLOTHING/FURNISHINGS

6.8.1 Until 1982, food remained the major item of consumer expenditure, when housing and transport/communication, in that order, became more important. Expenditure was higher on meat than on any other food, and the next largest items of expenditure were on milk, cream, cheese and bread and other cereals. Expenditure on alcoholic drink, increased by 19% in the last decade. Changes in food consumption patterns are shown by the following figures

UK consumption of major food items
(ounce per person per week)

	1971	1981
Liquid milk (pints)	4.74	4.01
Butter	5.53	3.69
Margarine	3.15	3.69
Sugar	15.80	11.08
Beef and lamb	13.37	11.21
Por~~e~~k and poultry	2.69	11.12
Fish	5.15	4.92
Potatoes	49.18	41.87
Bread	35.76	31.23
Vegetables (excl. canned)	30.80	27.73
Fruit (excl. canned and dried)	20.07	19.97
Tea	2.39	1.98
Instant coffee	0.44	0.52

(Source: Annual Abstract of Statistics, 1983)

6.8.2. Consumption of liquid milk has fallen by 20% in the last two decades with most of that decrease recently. Consumption of butter has shown the most dramatic decline, by 43% in the last decade, whilst the amount of margarine eaten has increased by 38%. The numbers of eggs eaten has also decreased by about 30%. Concerns about adverse health effects of an over consumption of dairy products may have played a part in such changes, although there may be other reasons such as price, demographic or other change influencing food preference etc. Poultry and pork have replaced beef and lamb as the major sources of meat in the diet, the main reason being more favourable pricing of the former due to improved and agricultural systems which have had a greater impact on the production of "white" meat. The last twenty years has also witnessed a reduction in the amount of starchy and sugary food eaten. For whatever reason, therefore, there has been a perceptible change to a "sounder" diet.

6.8.3. The foregoing changes have been emphasised in recent years by a growing interest among consumers in nutrition and healthy eating habits leading to demands and production of food with special characteristics, for example, food with lower fat and salt, higher in fibre content. There has also been a growing minority of the population who prefer not to eat meat and this has been reflected to some extent in the food products available. Such attitudes stem from perception, whether based on accurate scientific evidence or not, that there is a link between diet and health, for example, that between high blood pressure and obesity. ACARD suggested in the report "The Food Industry and Technology" that nutritional understanding in the general public would increase and that food manufacturers would need to respond to that.

6.8.4. The food market is continuing to diversify. At one end there is a requirement for more variety and quality, and at the other for convenience, speed and ease of preparation. Such diversity is also partly a result of changing lifestyles, family composition, attitudes in society and a more multi-racial population. The family set meal has been replaced by more informal eating arrangements in which food requirements often differ. More people are eating out. Greater emphasis on speed and ease of preparation of food has produced new forms of convenience food and also equipment such as microwave ovens, fast cookers, etc. Increasing travel abroad has encouraged people to experiment and try non-traditional foods, to which food companies have responded in terms of products. Increasing demands for quality, freshness and naturalness in food will require manufacturers to develop and apply new technologies for manufacture to satisfy both national and international markets. Biotechnology will have an increasing impact on the supply of materials for use in foods.

6.8.5. At the primary supply level, the increasing surplus of agricultural commodities gives rise to concern and is a problem which will require tackling at a more fundamental level than has yet been attempted. Approaches may well be largely of an economic nature but technical solutions could make a major contribution. There are pressures also for development of agricultural commodities whose compositions are more closely related to the requirements of food manufacture and the consumer. Another aspect to this problem is the relative over supply of food crops compared with a massive undersupply of forest products from indigenous land resources. Although it is not anticipated that fuel from biomnass will be economically feasible for some 50 years or so, demand could increase for production from land of a number of resources, and the timing of such production will depend on changing economic circumstances.

6.8.6. Increasingly people are taking a broader view of the countries land resources and what they are used for. Access to open space and the countryside coupled with concerns about the way the landscape and natural environment are being altered by farming will require further consideration of approaches in and the suitability of many modern agricultural practices. Recently public attention has been focussed on the welfare of animals in intensive production systems and the use of genetic engineering techniques in farm animals. Such concerns are likely to continue and are factors which technological development cannot ignore.

6.8.7. Consumption of fish has increased over the period 1976-82 almost by the same amount as it decreased in the previous 5 years, as shown by the following figures.

	Fish consumption (oz per person per week)		
	1971	1976	1982
Fish, fresh and processed	3.61	2.67	2.76
Canned fish	0.63	0.65	0.63

Fish and fish products, frozen	0.91	1.26	1.65
Total	5.15	4.58	5.04

(Source: National Food Survey)

It has been suggested that if the UK follows the USA in seafood consumption, then the amount of fish eaten in the UK could well increase in the future. A significant development in the last decade has been the rapid expansion of fish farming. The largest development has been witnessed in trout production; thus production of rainbow trout has increased from about 1000 tonnes in 1972 to 10,000 tonnes in 1983 and now exceeds that of some important sea species such as hake, sole, halibut. Farmed salmon, carried out almost exclusively in Scotland, has increased from about 100 tonnes in 1972 to 2,500 tonnes in 1983 which is greater than the 1,300 tonnes from sea-fishing. A small amount of turbot and sole are produced by fish-farming, and about 200 tonnes of eels. In real terms the price of fish produced from fish farms has remained fairly steady. On present trends, further expansion in fish farming activities appears likely; scientific advances and improvements in production techniques will assist the growth of the industry and provide new aras for fish farming of other species. Science and technology could have a major contribution to play in the controlled farming of sea-water fish in captivity, and the natural harvesting of the oceans.

6.8.8. Consumption of alcohol has increased significantly in the last decade, expenditure increasing by some 19%. Figures showing this trend for the period 1973-80 are as follows:

	1973	1980
Beer	197.3	206.1
Spirits (100% alcohol basis)	2.5	3.2
Wine	9.1	14.3

(Source: Brewers Society)

Beer is still by far the most popular alcoholic drink in the UK, although there has been a significant decline in beer consumption in the last two years. Whether this is due to short-term recessionary effects or the rise in popularity of other types of drink principally wine and spirits is uncertain at present. The beer market itself has undergone a transition in the last decade, with lager-type beers increasing their share of the market from about 10% in 1971 to some 31% in 1980. Other major changes have been the growth of sales of beer in disposable containers both metallic and non-metallic at the expense of returnable bottles, and the increasing sale of beer through shops and supermarkets for consumption at home. After showing steady growth over the 1970s, consumption of Scotch whisky levelled off in 1980. Such an effect has also been seen worldwide, which reflects a movement towards white spirits and wine consumption at the expense of whisky; the extent of this trend has yet to become apparent. So far as white spirits are concerned, consumption of gin has shown a small but steady increase whereas consumption of vodka has risen more sharply. The growth in the absolute level of wine consumption is an important feature of the UK drinks industry. However, per capita consumption at 14.3 pints per annum is minimal when compared to some other European countries with consumptions of over 150 pints. Another feature of recent years has been the growth of the UK cider market, but consumption levels are only a fraction yet of those for beer. A major phenomenon of the drinks market in recent years has been the rapid rise in consumption of soft drinks, although production dipped slightly at the beginning of the 1980s. In 1971 some 318 and 1236 million litres respectively of concentrated and unconcentrated soft drink were produced compared with 512 and 2195 million litres in 1981.

6.8.10. The textile and clothing industry is a major sector of the economy that has contracted considerably in recent years, much more than in othe developed countries. This industry is nearly as large as the motor vehicle manufacturing industry, and was in 1980 the third largest manufacturing contributor to UK export earnings. The decline of the industry has resulted from competition from developing countries who have increased exports to developed countries under the first two Multi-Fibre Arrangements. Through the 1970s, the industry prospered through innovation and market development, and became, for example, a world leader in fabric for vehicle interiors, and textiles for use in civil engineering. It became established as a significant supplier of clothing to markets world-wide. Its present demise is a result of economic circumstances since the late 1970s.

6.8.11. In March 1983, the British Textile Confederation produced a plan of action to improve the position of the industry. A particular point made in the plan was the reduced career attractiveness of the industry because of its contraction. It was recognised that further modernisation was required which might include as yet unforseen technological advance but this would require a flow of skilled managers, technologists and scientists. Attention was drawn to proposed reductions in availability of higher education in textile skills of all kinds, at both university and college levels, and to the need to ensure that facilities were available for further and higher education in all textile skills, and is associated chemical, electronic, and engineering disciplines.

6.8.12. A major cause of the inability to withstand competition has been poor marketing and fashion performance, and although some areas have performed well the overall technological performance of the industry has not been outstanding; the textile machinery industry has lost ground at home and abroad. If the industry is to be successful in the future it will need to pay greater attention to marketing and fashion, as consumers require garments which are more individualistic and search for clothing different from that produced for the mass market. Installation of advanced machinery, as has happened in the USA, will also assist in increasing competitiveness. The use of sophisticated sensors and mircoprocessors on automated sewing machines will increase flexibility in garment assembly and ability to respond to changed fashions or to develop new fashions. Advances are likely also in yarn and fabric production, particularly in the weaving process. Yarn and fabric producers will be required to continue to diversify into non-traditional processes and products. Opportunities are offered by new polymers for widening the use of non-woven and non-assembled technologies into new product areas with improved quality, for example, industrial linings currently make use of such technologies.

Computer control of the manufacturing process from materials handling to inventory control, will increase flexibility in textile and clothing production to satisfy diverse and rapidly moving markets, and would allow a more flexible and decentralised pattern of organisation of the industry which might increase its competitiveness.

6.8.13. There are considerable opportunities for innovation in clothing, textiles, and fabric manufacture and use. Such potentials lie in imaginative manufacture using fibres currently available rather than in development of new fibres and fabrics, although improvements could be made in current fibres by increasing wearability. Progress is needed in the assembly of fibres, for example, by development of techniques for the incorporation of foam in clothing materials. Waterproof fabrics which can "breathe" also offer possibilities. The properties in manufacture and final products of non-woven materials are not sufficiently understood to allow their more widespread use. The features and qualities of woven materials need to be examined in relation to their incorporation into cheaper materials. So far as fabrics and materials for home-furnishings are concerned, safety aspects have been an important consideration in recent years, for example, move away from foam-fillings which are a fire risk. Safeness in use will continue to play an important part in textiles for clothing and furnishings.

6.8.14. Although not strictly related to either food or furnishings, brief mention is made of trends in cosmetics here because it is generally linked to them in terms of consumer spending habits. It is an important if small industry, roughly worth £500 milion on retail sales compared with about £800 million for sports and sport services and opportunities exist for technology to produce new and improved products. Although most cosmetic companies in the UK are foreign owned which accounts for about 90% of UK sales some 85-90% of cosmetics sold in the UK manufactured here. Chemists (47%) and department stores (20%) account for the bulk of sales but some 20% is sold door-to-door and with the competitive pressures on the high street chemist it will be of interest to see if this ratio is maintained in the future. The market in cosmetic products is made up of fragrances (40%), skin preparations (24%), make up (22%), mens toileteries (8%) and miscellaneous products (6%). So far as frangrances are concerned recent trends have seen a decline in talcs and powders and growth in bath oils, creams and essences, whilst perfumes and scented waters have remained fairly static. The skin care preparations market has been a significant growth area in recent years, with increasing desire to maintain "young" skin for longer in life and demand for proprietary facial preparations to treat skin problems. Cosmetics for particular ethnic groups have also appeared recently. For the future, there is considerable scope for scientific advance and technological progress to have considerable impact not only on manufacture of current cosmetic products but also to open up new markets. Thus new chemical synthetic and biotecnological process could be used to produce the components of cosmetics, and advances in basic understanding of cellular chemistry could lead to products for treatment of hair loss, skin ageing, etc.

6.9 EDUCATION

6.9.1 The school population has been affected by the high birth rate in the 1960's, and low birth rates in the 1970's so that trends in school numbers in recent years, and projected trends are as follows:

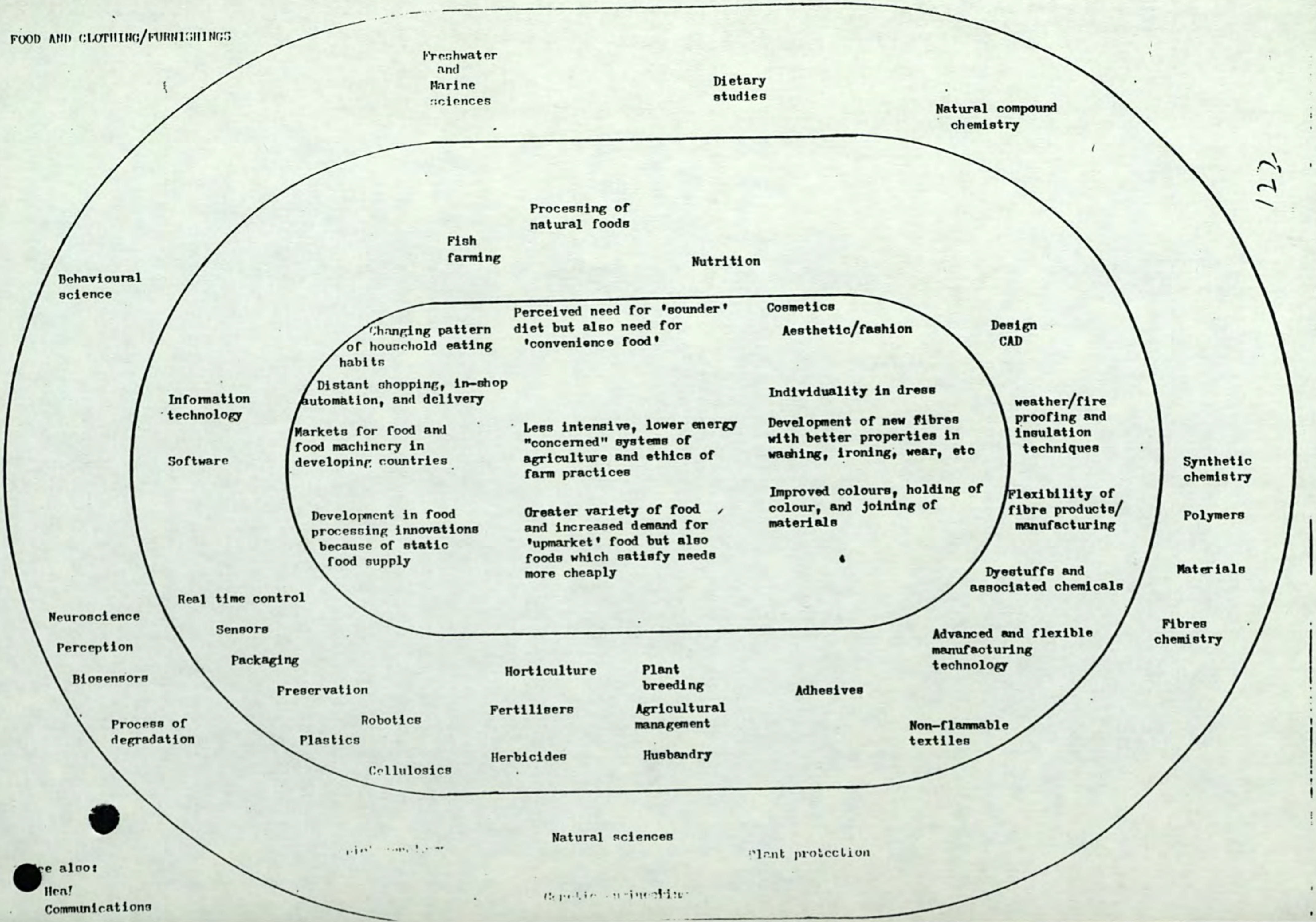
Numbers of school pupils in the UK (thousands)

	1971	1982	1991 (Projected)
Nursery Schools	50	91	102
Primary Schools			
Under 5's	301	455	488
Other	5601	4506	4278
Secondary	3555	4559	3401

(Source: CSO Social Trends 14, 1984, HMSO)

Thus rolls in both the primary and secondary education are projected to fall by the turn of the decade although a slow rise to the end of the century is probable after that. The major feature of secondary education in the last decade has been the emergence of the

FOOD AND CLOTHING/FURNISHINGS



Perceived need for 'sounder' diet but also need for 'convenience food'

Changing pattern of household eating habits

Distant shopping, in-shop automation, and delivery

Markets for food and food machinery in developing countries

Development in food processing innovations because of static food supply

Less intensive, lower energy "concerned" systems of agriculture and ethics of farm practices

Greater variety of food and increased demand for 'upmarket' food but also foods which satisfy needs more cheaply

Cosmetics

Aesthetic/fashion

Individuality in dress

Development of new fibres with better properties in washing, ironing, wear, etc

Improved colours, holding of colour, and joining of materials

Processing of natural foods

Fish farming

Nutrition

Design CAD

weather/fire proofing and insulation techniques

Flexibility of fibre products/ manufacturing

Dyestuffs and associated chemicals

Advanced and flexible manufacturing technology

Non-flammable textiles

Adhesives

Plant breeding

Agricultural management

Husbandry

Horticulture

Fertilisers

Herbicides

Cellulosics

Plastics

Robotics

Preservation

Packaging

Sensors

Real time control

Software

Information technology

Freshwater and Marine sciences

Dietary studies

Natural compound chemistry

Behavioural science

Synthetic chemistry

Polymers

Materials

Fibres chemistry

Neuroscience

Perception

Biosensors

Process of degradation

Natural sciences

Biotechnology

Plant protection

Genetic engineering

ee also:
Heal
Communications

comprehensive school as the dominating institution, and the numbers of school leavers entering further training schemes directly from school has shown a steady increase. In 1981/82 some 6.9% of boys and 4.9% of girls leaving school went to university, whilst a further 16.9% of boys and 27.8% of girls went into some other full-time further education, leaving 76.3% of boys and 67.2% of girls school-leavers available for employment.

6.9.2 The subject groups in which higher education qualifications were obtained in 1981 in the UK are as follows:

	Higher education qualifications (%)		
	University and CNAA	Other higher education awards	Total
Education	6	48	16
Medicine, dentistry and health	7	1	5
Engineering and technology	15	35	20
Agriculture, veterinary science and forestry	1	1	1
Science	19	10	17
Social, administrative and business studies	26	1	20
Architecture and other professional vocational subjects	3	3	3
Language, literature and area studies	10	-	7
Arts other than languages	13	-	10

6.9.3 In recent years some 30% of first degree graduates have gone on to further education or training. The next most important destination of such graduates was to education or public service, with industry and commerce in third and fourth positions respectively. Some recent figures have shown that only in engineering and technology does the demand for graduates outstrip the supply, and social, administrative and business studies supplied the greatest excess of graduates over the apparent demand.

6.9.4 With the consolidation of the comprehensive school system and rapid expansion of the higher education system in the last two decades it seems likely that attention will be increasingly focussed, in the future, on the type of education provided by such systems and the output in terms of national requirements. Indeed, that process has already begun with recent changes to school curricula and approaches to examinations in secondary schools and the current debate initiated by the University Grants Committee on the role of universities.

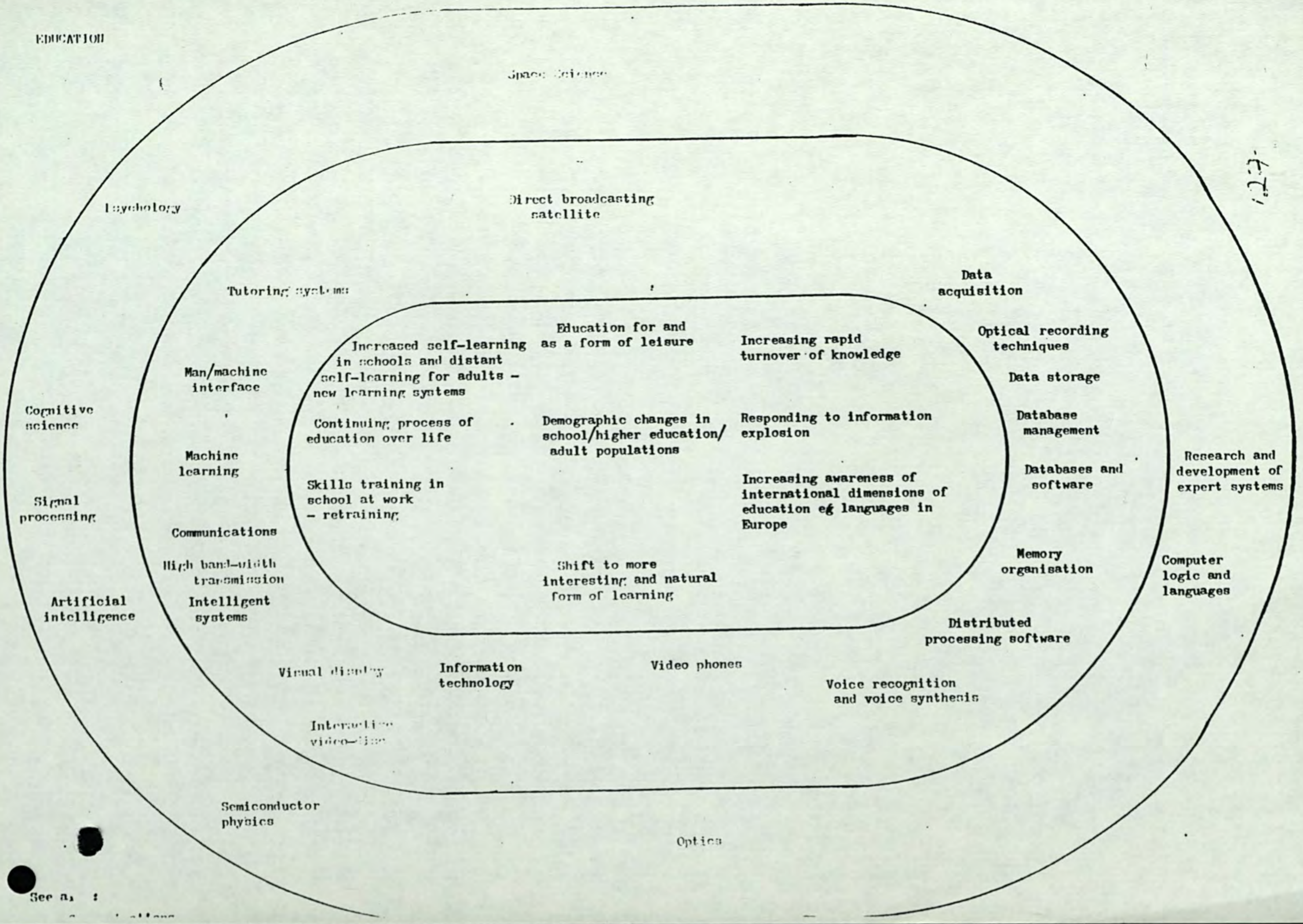
6.9.5 The Finniston Report highlighted the changes which had taken place in the education of engineers in recent years. Whilst the number of engineers trained in universities had more than doubled as a result of the Robbins Report on higher education, there was a relative lack of practically trained engineers available to industry. A better integration between the theory and practice of engineering in education and training was required. The importance of continuing education, and the need for periodical retraining of qualified engineers was emphasised, but the universities have so far been slow to recognise the opportunities which this might present. Universities may well adopt a more flexible approach to their own academic staff and in order that such staff may stay at the forefront of their field might seek the exchange of academic staff with colleagues in industry. Another approach in scientific disciplines would be for universities and industry to develop joint laboratories under joint sponsorship.

6.9.6 The rapid change in application of technology to all sectors of work and society, will increasingly require more and more people to be retrained during the course of a career; many large companies and organisations in the USA are already making provision for retraining and education of employees. In this context, the UK is lagging behind other countries, for example, West German industry retrains many more workers than does the UK. Emerging school-leavers and graduates will no longer be able to regard school or university as the place at which their formal education is completed but will need to become used to further periods of education and retraining. It will be particularly important in the first stages and subsequent stages of secondary and higher education that the approaches to training and skills development are relevant to the employment opportunities available and creation of employment opportunities. One of the problems of increasing high technology is the maintenance of such systems and it will be necessary to ensure that adequate skills are available for maintenance of equipment ranging from nuclear power stations to cars and home electronics. There is increasing evidence that the education system is inadequate to cope with the need for skilled technicians and engineers when the demand for such skills is likely to increase over the next two decades. Such a demand may also be related to the rapid increase in numbers of women seeking careers in recent years. Although women have sought to build careers mainly in education, the law and service sectors, there may be greater opportunities in future in technically related employment.

6.9.7 As more sophisticated communications technology is developed distant learning will become of increasing importance. A variety of applications might be envisaged ranging from basic education and training to transfer of technology to already trained people. Such systems will be used increasingly in formalised institutional education, starting initially as supplements to such systems, but will probably find their greatest application in more distributed education, for example, retraining, education as a leisure form, etc.

6.9.8 A major impression which emerges from the current education scene is that the content and approaches in formal systems of education appear increasingly anachronistic and are often inappropriate for personal and national requirements in terms of skills and abilities for later in life. A large part of implicit education now takes place after formal education has ceased. Society and employment opportunities increasingly require greater flexibility on the part of individuals to have training and education which makes them more adaptable to change. Early education should not be restrictive on such flexibility and might be viewed more as the development of a learning process and acquisition of knowledge for subsequent training and retraining needs. Educational institutions have yet to address adequately, the urgent problems of educational needs for career flexibility and the increasing amount of knowledge to be acquired during education. Education is also an expensive activity and pressures are increasing to reduce costs. Such pressures will require consideration of traditional approaches to education and learning methods. In our opinion, the development of new approaches to teaching is extremely important; communications technology in the form of machine learning and the interaction of computer software with individuals will be crucial to such processes. Another feature of the education scene, is the apparent mismatch between the output in terms of abilities and skills, and subsequent needs of society and employment. In schools the form and content of education is inadequately linked to the level of ability, which makes for inefficiency in the deployment of resources, inhibits the development of interests at different levels, and reduces the spectrum of individual interests and abilities emerging from such a system.

EDUCATION



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6.10 LEISURE

6.10.1 Over the two decades from 1962 to 1982 there has been a significant change in the amount of time spent at work with consequent increase in the time available to people for leasure pursuits, as the following figures show:

	Time in employment (average for full-time males) 1962	1982
Working week (hours)	45	39
Holiday entitlement (days)	14	28
Working life (years)	48	42

(Source: Dept Employment and Henley Centre)

6.10.2 Official statistics on participation and trends in some leisure activities are available but they present only a partial picture of total activity due to the difficulty of measuring participation rates in many leisure activities because of their informal, infrequent, and seasonal nature. Such statistics also depend on the definition of leisure activity; the official approach is to regard leisure as activity which "people do when they are not in paid work, or at school or looking after the house and family". However many leisure activities, nowadays, are physically and mentally more exacting than the work in which people are employed and often are not concerned with entertainment or pleasure. We feel that greater consideration should be given to the word "leisure" because of the variety of situations in which it is used. Many "leisure" activities might, if the opportunity arose and with appropriate advice, be successfully exploited commercially. Such an approach would also be consistent with an increasingly IT based society. The notion that IT will increase the amount of leisure time available to people should in our view be discouraged. We would suggest that the effects of IT might be to increase the time available for people to participate in creative, social or cultural activities which will have rewards, possibly financial, depending on circumstances, attitudes and approaches. IN 1982, expenditure by the "average" household on leisure amounted to some 14.4% of total household expenditure. This is not a considerable amount and only housing, transport, and food expenditures at 16.5%, 15.8% and 15.3% respectively were greater.

6.10.3 Figures from the Media Year Book for 1983 demonstrate the rapid growth of television related durables in the last decade. Thus in 1983 some 82% of homes possessed a colour television set compared with 31% in 1974. About 35% of homes now possess two television sets, although a significant number of additional sets are black and white. By the end of 1983 approximately 25% of homes owned a video cassette recorder. The average person spends some 20-25 hours each week watching television compared with about 9.5 hours listening to radio. The amount of time spent listening to the radio has remained at much the same level in the last five years. But annual attendance at cinemas has fallen from 176 million in 1971 to 60 million in 1982 reflecting perhaps the increasing penetration in and viewing of television in households. Theatre attendance at about 37 million annually has remained fairly constant in recent years. Reading of newspapers declined through the 1970's perhaps because of the availability of news on television and radio. It will be interesting to see how much impact further developments in electronic communications will have on the print media in the future.

6.10.4 The hotel business is still, however, largely dependent on the domestic market as the following figures show:

Expenditure on Hotel Accommodation 1981

	UK residents	Overseas	Total
		£ million	
Holiday	2,000	335	2,335
Business	1,000	230	1,230
Other	165	235	400
Total	3,165	800	3,965

Demographic changes in the next two decades will see a larger retired population with increased levels of disposable income. Those people may well be more healthy than previous generations of elderly and have different attitudes to lifestyle in retirement. A reason for the declining domestic holiday trade, apart from holiday camps, may be a move away from the traditional family centred holiday, and this may well see the demise of the seaside hotel and boarding house, unless they diversify into new markets. Holidays are becoming more varied in nature, with an increasing tendency to take short holiday breaks throughout the year rather than one main holiday. The short-break market has been an area of significant development in recent years. However, domestic holiday-making is not now significantly cheaper than holidaying abroad, and may need to consider carefully soon the type of market which it seeks to attract and make appropriate changes to the services which they provide.

6.10.5 Participation in sporting activities of all types, both indoor and outdoor, has shown an increase, in some cases quite dramatically, in recent years. The increase has also coincided with increasing interest in non-sport related physical activity such as jogging, keep fit, walking etc. All these activities might be expected, if linked to improved diet and smoking habits, to be reflected, in the long term, in improved health and less demand on the medical services. There has also been a major spin-off in the demand for sports equipment and infrastructure, and many major companies have capitalised on that demand. The physical fitness trend may not be as strong as in the USA but it is likely to remain a permanent feature of lifestyles in the future.

6.10.6 So far as trends in sport activities are concerned, the General Household Survey shows a picture of relatively little change in activities in recent years. Thus, walking has been the most popular activity followed by swimming, darts, billiards/snooker, angling, football, golf, tennis and table tennis in that order. The 1970s saw the growth of many new sports such as squash, basketball, badminton, judo, canoeing, yachting, gliding, etc but the rate of growth has not been sustained in the 1980s. The following gives figures for the ten sports which showed the largest expenditures by participants in 1980.

	Estimated expenditure (£ million)		
	Products	Services	Total
Yachting/rowing/canoeing	224	20	244
Golf	73	54	127
Swimming	50	29	79
Billiards and Snooker	1	48	49
Football	35	11	46
Squash	19	27	46
Riding	14	31	45
Tennis	36	9	45
Angling	34	10	44
Athletics	21	7	28

(Source: Martin and Mason, 1980)

Public tastes in sporting activities are variable and changeable, fashions come and go and individuals tire of one sport and take up another. Such changeability should provide the spur for development of new products and services for sporting activities and the UK sports industries should be on the look out for further exploiting present tastes and fashion and be on the look out for sport and services in other countries which might be exploited in the UK.

6.10.7 In terms of household expenditure, spending on holidays comes second after alcoholic drink in the list of priorities for leisure activities for most households at all income levels. So far as the holiday habits of British residents are concerned, the major trend in the last decade has been the increase in holidays taken abroad, numbers have almost doubled, whilst the numbers holiday-making in the UK have remained fairly static. However fewer British people stay in hotels when holidaying in the UK, though a compensatory increase in foreign tourists and business people staying in hotels has probably taken place.

6.10.8 But many people are not interested in sport related activities. The proportion of peoples time spent in non-sporting activities has in general been little documented, but circumstantial evidence, from the amount of local authority and other vocational courses available, suggests that interest is not insignificant. Leisure-related education is a rising trend, as evidenced by increasing demand for Open University and other courses. Participation in such courses may initially be for reasons of purely personal interest but opportunities to exploit the experiences gained may be presented later. Demand for self-improvement in this way seems likely to increase, and the educational authorities concerned may choose to respond by providing courses of greater relevance to employment opportunities and technological needs.

6.10.9 As discussed earlier, overall trends show an industrial population which has virtually ceased to grow, and continuing low levels of economic growth in industrialised countries. Patterns of economic activity are changing rapidly, the pressures towards a more informal decentralised work pattern have been referred to. Ownership of technology by households in terms of electronic equipment such as computers, television, video-recorders, domestic electrical equipment, etc is steadily increasing the amount of investment contained in households and value added is being created by households for themselves. Instead of work and leisure being at opposite ends of a spectrum, the distance between work and leisure, and indeed the separation of work and leisure places is beginning to close. It has been argued that formal employment is not a necessity of human nature and as the amount of time spent in employment diminishes different structures to life-cycles will emerge. One notion suggested was that work may be approached in a way which has been traditionally associated with leisure, and leisure activities will have routines, disciplines and formality relevant more to conventional employment. As distinctions between work, leisure and education decrease, boundaries between traditional work and leisure time may tend to dissolve. Thus an area for employment growth in the future is likely to be leisure services and patterns of time at work in such activities may vary markedly from the working time in current conventional employment.

6.11 TRENDS IMPINGING UPON STRATEGIC SUPPORT

6.11.1 To draw this chapter to a conclusion we would suggest a number of indicators related to trends in social, economic and scientific affairs are relevant to the possible emergence of new areas of strategic science. On the basis of only a brief investigation, a list of more important items would include:

i. Atrendof sustained development in a particular area of science, suggesting rapid gains in the fundamental understanding of a particular set of phenomena.

ii. The emergence of connections at the interface between hitherto distinct scientific disciplines.

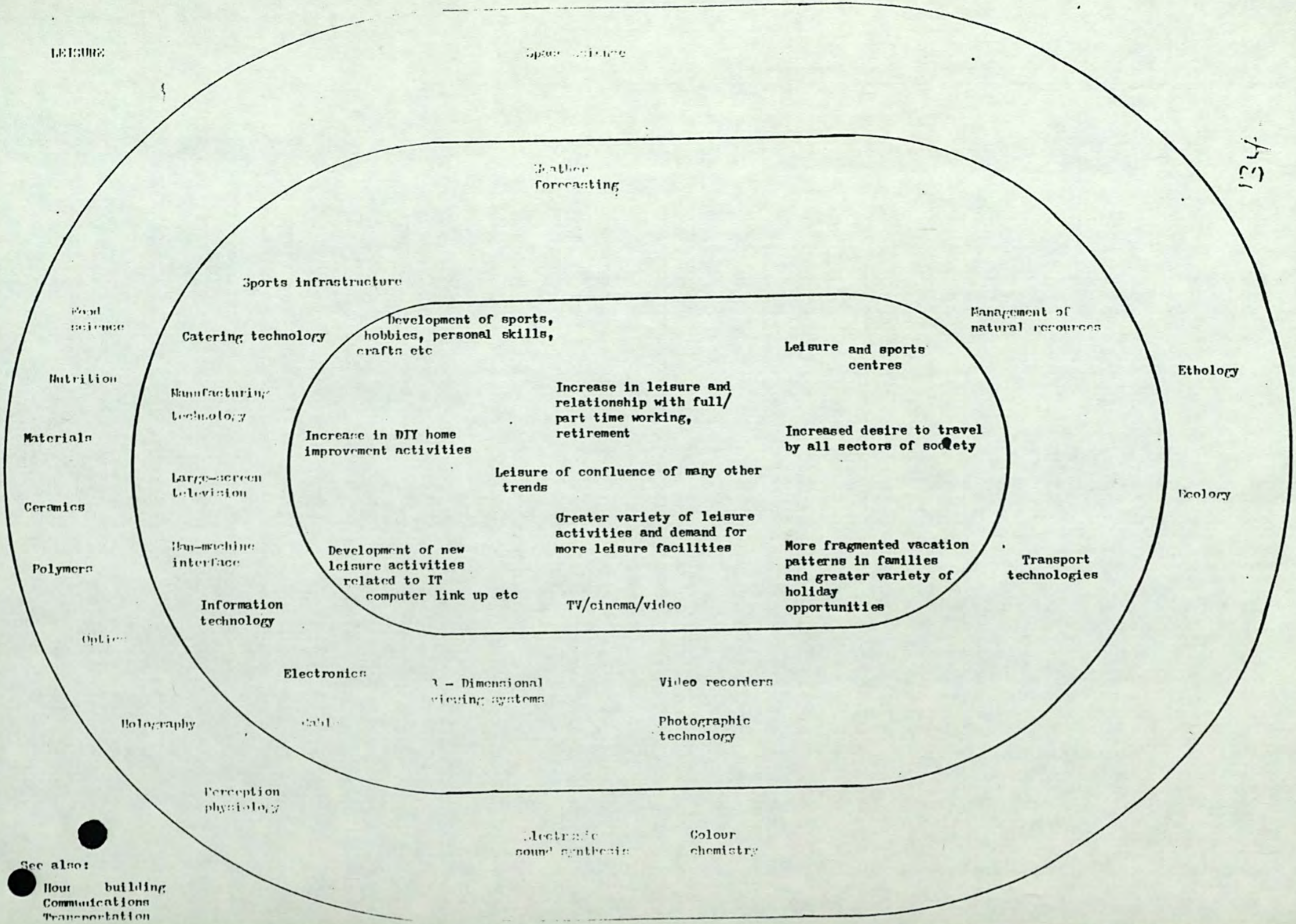
iii. Population growth and age structure trends - perhaps the easier of the variables to forecast over a twenty year period.

iv. Economic growth in relation to the way consumer budgets vary with respect to the level of per capital income.

v. Trends in the balance of demand and supply of energy resourcews and industrial raw materials, with the implied effects on the relative prices of these productive inputs. (Chapter 4)

vi. Social attitude, environment and work style trends discussed in previous chapters.

LEISURE



Space science

Weather forecasting

Sports infrastructure

Food science

Catering technology

Development of sports, hobbies, personal skills, crafts etc

Management of natural resources

Leisure and sports centres

Ethology

Nutrition

Manufacturing technology

Increase in leisure and relationship with full/part time working, retirement

Materials

Increase in DIY home improvement activities

Increased desire to travel by all sectors of society

Leisure of confluence of many other trends

Large-screen television

Ceramics

Ecology

Greater variety of leisure activities and demand for more leisure facilities

Man-machine interface

Development of new leisure activities related to IT computer link up etc

More fragmented vacation patterns in families and greater variety of holiday opportunities

Transport technologies

Polymers

Information technology

TV/cinema/video

Optics

Electronics

3 - Dimensional viewing systems

Video recorders

Holography

Cable

Photographic technology

Perception physiology

Electronic sound synthesis

Colour chemistry

See also:

House building
Communications
Transportation

CHAPTER 7 - SOME EXPLOITABLE AREAS OF SCIENCE

7.1.1 This chapter is essentially the core of the report, and in it we describe ~~the~~ some areas of science which we consider to be of major importance for the future. The areas were arrived at by a process of interaction between the members of the group, those consulted during the programme of visits, and other sources of expertise within the scientific and technological community. In many of the areas described, a clear unaninimity concerning the scientific field with potential was quickly apparent whereas in other areas opinions differed. For each area we have attempted to give our justification for its importance. ~~We also caution at the outset of the chapter that for very practical reasons our survey of areas can in no way be considered to be completely comprehensive and this should be borne in mind when reading the chapter~~.

7.1.2 It was quickly apparent to us that some scientific developments were so fundamental as to be of key importance to a very wide spectrum of scientific advance. Thus in the physical sciences, greater understanding of and applications of photon phenomena will have consequences of equal magnitude to those which the electron has had in recent decades, and photon-electron reactions will provide the basis for exciting advances in many of the areas to be described. Similarly, in biology a greater understanding in molecular genetics will have far-reaching effects in many different fields. Also, scientific progress relies on discoveries and applications of other disciplines. Thus science has always had a close association with mathematics and towards the end of the chapter we outline the fields in mathematics which we consider will have a major impact on the scientific process.

7.1.3 The science areas which we considered tended to group themselves naturally into three areas, as follows

a. The acquisition and handling of information

b. Energy, materials and manufacture

c. Natural processes

As we have discussed in several places, scientific endeavours are not mutually exclusive and many of the areas described interact with other areas; however we have not attempted to reference such interactions in any great detail. We had wished to include a fourth area concerned with areas of potential in the social sciences but time has not allowed us to do this, but we consider that this should be addressed at a future date.

7.2 THE ACQUISITION AND HANDLING OF INFORMATION

7.2.1 Introduction

7.2.2 The government of a ~~complex~~ modern society depends on its ~~knowledge~~ ability to handle a complex database. The planning of a business enterprise depends on the data it gathers on markets and competition. The treatment of a malfunctioning body depends on the diagnosis. The science of data handling has progressed greatly in the last ten years largely due to an improved capability for processing information in electronic systems. The improvement in processing has justified improvements in acquiring this data, for the two should go hand in hand - there is little point in gathering data which cannot be used.

7.2.3 In the context in which we analyse the topic, we consider "information" as made up of both data and knowledge and a series of rules for combining them. It is obvious that humans exploit all three in deciding on a course of action. Computers are not yet as good as humans in coming to judgements because programming is still at an early stage of development. The handling of information may be broken down into five parts, each a subject in its own right. These are:

1. Acquisition
2. Organisation
3. Processing
4. Transmission
5. Exploitation

7.2.4 The acquisition of data depends on sensors, which are now becoming extremely sophisticated, often involving an overlap between two or more sciences, chemistry, physics, biology and electronics. Not only is progress being made to measure directly parameters which were previously the target of difficult laboratory experiments, but also in detecting traces of elements or molecules - sometimes as few as five atoms. Moreover, we can do this, with exceptional rapidity, often in real time.

7.2.5 The organisation of the information is an important step in understanding its importance. It can be classified and compared with information already held in the system memory. The size and management of the knowledge base now becomes critical. Cognitive Science and Artificial Intelligence will play key roles in the improvement of information handling.

7.2.6 Data processing is generally recognised as the feature by which electronics computers have made their major impact. But present computers process information step-by-step, or sequentially, by the so-called Von Neumann process. Future progress may well depend on the ability to master parallel processing techniques, with processing units distributed around the computer, or by optical processing.

7.2.7 Transmission of information locally, nationally, or internationally is fundamental to data handling. There have been two hardware developments which have completely changed the nature of data transmission, and will determine the shape of the next ten years. The first is optical fibre transmission, and the second satellite communications. The ability to observe the world as a whole gives us not just a system of communications but also an ability to sense remotely, to gather data which was previously not available.

7.2.8 The final stage of exploitation can be divided into two classes. Sometimes data are exploited in a machine, such as a robot, without human intervention. More often, a human is expected to interact with the system. The conclusions emerging from the electronics are presented to the eye or ear of the operator. This interaction can be cyclic, particularly with voice command to the electronic system acting as the input.

7.2.9 It must not be forgotten that much of the progress expected in data handling will depend on the development of new materials. These are the subject of a separate sub-section.

7.3 DATA ACQUISITION

7.3.1 Sensors

7.3.2 The present standard of sensors and instrumentation in most of UK industry is weak and rudimentary except in the growing area of biotechnology. Therefore, it is hardly surprising that the majority of organisations which we have visited have highlighted the need for improved understanding and development of sensors. In order to produce a reliable device it is important to consider the overall system. That is, the transducer and the associated instrumentation cannot be divorced from the sensor at the front end. Moreover, advances in microprocessor instrumentation now permit more sophisticated control of the sensor, thereby conferring greater reliability and specificity.

7.3.3 Several Research Council sub-committees have expressed the requirement for programmes of fundamental research directed towards the applications of specific sensors: for example, medical scientists are concerned about the development of biosensors which could lead to completely new clinical procedures; chemical engineers are developing an interest in the use of sensors for process control; and biotechnologists require improved sensors for detecting minute quantities of organic molecules. There is no doubt that research will need to be multidisciplinary. It will impinge on the activities of solid state physicists, electronic engineers, biologists and enzyme, polymer; and electro- and software chemists. In some areas such as speech input and recognition, it will require signal processing skills of the micro-electronics engineer to integrate the sensor and the detector on the same microchip. The development of sensory techniques will also have an impact on the production of robots in manufacturing technology.

7.3.4 An indication of the wide range of basic scientific research required for the development of improved sensors can be gained by studying requirements in the medical field. Here, priorities vary from cheap and reliable in-vitro sensors for use in the home or hospital ward, to more sophisticated ones for in-vivo investigations, eg blood monitoring. Chemically sensitive semiconductor devices utilizing antibody-antigen reactions and novel organic materials which react highly specifically and reversibly (such as receptor proteins) are required. In order to produce biological sensors it will be necessary to develop surfaces compatible with proteins and other biological molecules, to investigate means of immoblizing ionophores in thin films and control the deposition of the active-species onto specific sections of a micro-device. Research will also be required into the physical properties of novel transducers to be used in conjunction with the sensor to provide reliable, on-line, real-time instruments, eg ion sensitive field effect transistors, optical fibre sensors and piezo-electric devices.

7.3.5 New Analytical Techniques

7.3.6 Advances in instrumentation and in analytical techniques applicable in many disciplines continually emerge as a result of the discovery of new physical effects and principles. We only describe briefly a few examples here and the reader is advised to consult the published literature for more information. For example, the resolution of electronic microscopes is being greatly extended, novel X-ray techniques are emerging based on synchrotron storage rings, nuclear magnetic resonance is now being used successfully in tomography, and surface analytical techniques such as photoemission are currently being refined for the study of thin films and catalysts.

7.3.7 Contemporary micro-electronics is already making powerful demands on existing methods for characterising materials and devices. Molecular electronics will demand molecular scales of resolution in chemical analysis; new techniques are required to study ultra-thin film on substrates, solid-liquid interfaces, surface phase transitions, low dimensional structures, nanomole quantities of molecules etc. UK physicists have an excellent reputation in this type of research which ultimately leads to a profitable export industry in high quality instruments. The UK has been and remains a world leader in the production and export of mass spectrometer and photoelectron spectroscopic equipment.

7.4 ____ ORGANISATION

7.4.1 Memory

7.4.2 Data storage for computers represents the largest single area of activity in current semiconductor research, the objective being to produce larger and faster memories, with corresponding reductions in the `cost per bit´ of information stored. There is worldwide recognition of the need for this improvement in memory technology and a large number of major companies are carrying out research in the area. One result of this wide recognition is that memory products have become a commodity on a worldwide scale with cyclic episodes of shortage and glut.

7.4.3 Memories however form an essential element in all computers and availability is of fundamental importance. The current emphasis on support for this work given by the Alvey committee acknowledges the key strategic importance of UK sources of this commodity to reduce vulnerability to fluctuations in supply from Japanese and American sources.

7.4.4 In addition to semiconductor based memories the exceptionally large capacity available in optical memories (laser/disc systems) is beginning to be the subject of significant research work. There is the prospect that for some applications large optical memories could displace semiconductors.

7.4.5 Memory Organisation

7.4.6 With the growing availability of ever larger memories there is increasing interest in the optimal organisation of these memories to make better use of the power available. The human brain is one evident example of the efficient organisation of a massive memory base in which information is retrieved by reference to the nature of the information rather than by making use of the memory 'address' in which the information is stored.

7.4.7 As a pointer to methods of organisation of large memories therefore much attention and current research is being directed in the area of cognitive science to begin to understand how the human brain and memory is used to achieve such functions as learning language, recognising speech, recalling experience, etc.

7.4.8. Knowledge Base Organisation

7.4.9 At a less anthropomorphic level, experience is rapidly increasing in the construction and manipulation of large accumulations of data and knowledge in existing computer databases. These provide plenty of raw material to enable experiments on the most efficient ways of gaining access to these data. Research on database management is of substantial commercial interest and will undoubtedly result in new products of significant commercial potential.

7.4.10 More recently, the value of accumulations of knowledge has begun to be recognised - or rules from experience of the form 'if A and B then C'. Work with knowledge sets of this sort is the basis of current research in the development and application of Expert Systems. This is widely recognised as an area with huge commercial potential enabling the provision of automated expert advice and guidance in areas such as medical, legal and military applications. With the assistance of such a system a comparative non-expert could provide the effective skill of a highly trained and experienced specialist.

7.4.11 Further development of this approach leads to the area of Artificial Intelligence where advice, decisions and subsequent actions may be made by the computer without the intervention of the human operator. Again it is widely acknowledged that the commercial potential of such systems is very large indeed.

7.5. PROCESSING

7.5.1. Computers

7.5.2 Traditional computers have been organised with one `central processing unit´(CPU) which carries out one instruction after another (generally operations on data which has been recalled from and is subsequently put back to memory). The sequence of instructions executed by the CPU is exactly determined by a precisely written programme which is predetermined by the computer programmer. This consequential instruction approach is generally known by the name of its inventor - von Neumann.

7.5.3 Current development activity in achieving greater processing power has largely concentrated on increasing the speed of operation of the CPU, enabling it to carry out more instructions per second, and also by increasing the scope and variety of the operations which it is able to execute. Although substantial increases in computer power have been achieved by this route there are clearly upper limits on achievable electronic speeds and on a sensible level of complexity for the processor.

7.5.4. Distributed Processing

7.5.5 With the availability of reasonably cheap semiconductor processors there has been a natural move towards the incorporation of more than one CPU in a single computer. The implication of this is that a number of commands or instructions can be executed in parallel, clearly giving rise to the prospect of greatly increased effective speeds for carrying out computing tasks.

7.5.6 However the majority of computer scientists have been trained along von Neumann lines and so have considerable difficulty embarking on the design and organisation of a machine which has no single CPU. There is no corresponding standard approach to the electronics organisation of such a computer and considerable amounts of research will be required to develop effective use of multiple distributed processors. In general terms, there is an assumption that in lieu of one very large memory and one powerful CPU, future computers will contain a large number of processing units each associated with a comparatively smaller segment of memory. Research work in this area has just begun and success in this area will be key in the successful design of the next generation of computers.

7.5.7. Software

7.5.8 Implicit in the move to distributed processing approaches is the need for a corresponding new generation of software. What is the optimum way to organise a set of commands to a whole series of processors so as to achieve the optimum execution of a computing task? Again, faced with liberation from the classic serial von Neumann approach there is no standard approach to adopt and at the present time the ability to define effective techniques. It is almost as though software writers had been taken back to the late 1940s and begun the task of organising a computer all over again.

7.5.9 As a result the whole area of software strategy, languages and operating systems for effective data processing is at a highly embryonic stage but is clearly the key to successful exploitation of fifth generation computers.

7.5.10 • Other Processing Approaches

7.5.11 For some particular applications specialised approaches to processing are possible. For example, it is currently feasible to take an optical image and manipulate it in the optical domain in order to extract fine detail information only. This need involve no digital data processing of any kind. Another application example is the identification of small changes between pairs of images which is a technique currently exploited in component stress analysis and in security applications.

7.5.12 Since optical records contain very large amounts of information when expressed in electronic bit terms, and there are vast amounts of image information which require processing (eg remote sensing satellites looking for weather or resources) then this technique extends the prospect of much more speedy information processing than would be possible in a digital computer. For this reason this and similar specialised techniques are the subject of much current research.

7.6. TRANSMISSION

7.6.1. The last twenty years has seen the habits of the community changing dramatically, with a move away from hard copy to electronic pictures, from books, and to some extent, newspapers to TV. This ability to bring information directly and cheaply into the home has by no means reached a plateau, consumer spending on TV and related hardware having doubled in the last ten years, and still increasing at 7% per annum in real terms. In spite of this growth, the consumer still spends more on letters and telephones than on TV, though expenditure on communications is increasing quite slowly. The improvements in the telephone system in the past ten years have been largely due to the substitution of modern hardware into the existing system, electronic exchanges, transistorised repeaters, microwave links. The first results of revolutionary changes, with progress in optical fibre systems and satellite communications, are beginning to be realised. These will lead to cheaper communications, particularly over long distances.

7.6.2. Optical Fibre Communications

7.6.3 It is now possible to impress a light signal into an optical fibre, and detect it 100 kms away, without any amplification en route. Moreover, the system gives many times more bandwidth than conventional cable, so that the same fibre will hold many conversations. The cost of communications, plus electronic techniques for compression of data, will make videophones practical for the consumer.

7.6.4 Improvements in fibres should allow repeaterless transmission under the Atlantic within 10 years, giving considerable competition to satellite systems. The ability of optical fibres to pass information along many close-packed channels without mutual interference can be exploited in many ways, one being in phased-array radar systems.

Remote control, either by free-space borne infra-red, or local miniature microwave systems, will become commonplace.

7.6.5. Satellite Communications

7.6.6 The increasing number and use of satellites in data transmission makes them an important feature for us to consider. A well-publicised use - as telephone repeaters - will come under increased competition from optical fibres. TV distribution in countries with a dispersed population will expand. A development with a pronounced effect on the Third World will be direct transmission from source to set. The low noise amplifiers that are necessary have recently become available, but their cost is still too high for widespread use in poor countries, who need them most. This will change.

7.6.7 However, satellites, and communication via them, can take on a more novel and extremely important role, for the satellite can be used on an observation platform for monitoring the atmosphere, the sea, and the land.

7.6.8 Remote Sensing

7.6.9 The development of sensors and even more of better processing equipment has made remote sensing a subject with great potential. There will, no doubt, be continued interest in remote sensing by aeroplane and further development of sensors which will make this a useful method for ad hoc service inspection. But the main interest centres on remote sensing by satellite because of the long term continuous surveillance of virtually all parts of the Earth's surface that is thereby possible . With electromagnetic sensors, information is yielded by every pass but with operational and infra red sensors a clear sky is required.

7.6.10 Remote sensing has been very useful in the geographical search for mineral and similar sources, although apart from perhaps changes in the time of day, and therefore illumination, an unchanging situation is viewed and, a very few satellite passes are sufficient. Further opportunities for such uses of remote sensors will depend on the development of new sensors. It is different when the object being viewed is changing. Meteorological satellites are well developed, but satellite study of the oceans for surveys, current and surface temperature is at an early stage; instrumentation, also, is not yet sufficiently advanced. The monitoring of the state and condition of crops such as sugar beet, coffee, sugar, wheat, giving greater understanding of the progress of plantations and agriculture will shortly arise with enormous implications for commodity markets. No doubt there will be political and legal problems, but it is expected that these will, in due course, be resolved.

7.6.11 The development of satellite borne sensors is an important field to which the UK has, so far, only made a relatively modest contribution outside specific areas of great scientific importance, such as, in particular, the upper atmosphere and some aspects of sea surface screening. There may well be scope for a broadening of the UK's effort in the sensor field.

7.6.12 Though it is easy to be distracted into believing that the satellite and its instruments are the most interesting parts of the enterprise, the downstream element is likely to pre-dominate. Computerised processing is required not only for the flood of data generated by a satellite, but particularly for embedding this new information in information only attainable by other sensors and methods. Ultimately this union will require a body of skilled interpreters. The development of interpretation techniques and methods, and producing sufficient numbers of people able to participate in these economically very important activities is a major challenge, as is the link with new customers and increasing their awareness of the value which can be added to their business by information obtained from satellites.

7.6.13 Navigation

7.6.14 The position of an object on earth can be determined extremely accurately by a satellite. Ship navigation can clearly benefit from a suitable system, but there are also possibilities for vehicle course control in areas where a local transmission system for navigation is impracticable.

7.7. EXPLOITATION

7.7.1. Exploitation and Interpretation

7.7.2 It is only by the practical applications of information acquisition and handling that users will see worthwhile benefits. The scope for useful applications grows as technical capability information handling grows. Early computers had limited (but speedy) number manipulation and storage capability and were therefore applied to critical calculation tasks, where the principle ability of the computer was directly exploited.

7.7.3 As mass storage of information became technically feasible, user applications were able to expand from high speed arithmetic to the holding and modifying of very large collections of information. Clearing banks' customer account records and airlines' reservation systems are examples of user operations, once performed manually, and now exclusively handled by computers.

7.7.4 Today we have available even more abundant storage and processing capacity enabling applications to be designed which go beyond large but intrinsically simple tasks, towards functions previously only carried out by the human brain, involving for example interpretation and judgement. As yet such applications are in early stages of development but their common characteristic is that they are used in an interactive mode with the human operator. Interim results are made available to the user, who then has an opportunity to confirm, challenge or modify those results before further work is carried out. A working dialogue between computer and user then allows a combination of the intrinsic abilities of each.

7.7.5 At present we are learning how best to store and handle information to support this dialogue. Considerable work is required to develop efficient ways to extract human knowledge in a form suitable for machine storage; to identify the rules used in forming judgements such that they can be automated; and to facilitate a ready dialogue between computer and user employing the ear, eye and voice.

7.7.6 A small number of such systems operating in limited environments exist at present but for example a full scope medical diagnosis ability equivalent to a GP will require at least a decade of development work.

7.7.7 Development will be required therefore in: knowledge elicitation; analysis of decision and judgement rules; high resolution visual displays which are capable of accepting user input via touch; voice synthesis techniques for audio output; speech recognition techniques to allow direct voice input and command; and natural language working to allow the dialogue to take place in common usage English.

7.7.8 The information filtered and assessed by the electronic systems emerges and is available for use. The direct use, in an automatic engine or robot, is discussed elsewhere, and will be considered no further. The indirect use, via a human being, is of critical importance. Two systems of output presentation are available, and both will make great strides in the next few years.

7.7.9. <u>Visual displays</u>

7.7.10 Optical presentation, the electronic display, has for many years relied on the cathode ray tube (CRT). The television monitor is a refined instrument, but its performance is now outstripped by the capabilities of the camera and the transmission and processing electronics. There is a demand for flatter systems, with a resolution of 1200 lines, and an area of 1 metre square. It is unlikely that a variant of the shadow-mask tube will meet this specification, but it would be surprising if some satisfactory system were not evolved in the next 20 years.

7.7.11 On a less ambitious scale, we can see flat panel displays dominating the market for word processors and vehicle instrument panels, and it is likely they will replace cathode ray tubes in most computers. They will take a fraction of the portable TV market, but their extra convenience will not generally outweigh the poorer picture they give.

7.7.12 Both types of display, CRT and flat panel, will become completely interactive, with the operator communicating by touch with the electronic system, and, possibly, to some home base. Home voting on important - or trivial - topics will be simple and cheap. This is likely to become an important technique for market surveys, home shopping and advertisement monitoring.

7.7.13 ~~A~~Oural Presentation

7.7.14 Research on speech output is now in an advanced stage, and the next five years should see the production of quite sophisticated systems, with a language capability not inferior to a person of average intelligence. The production of words is already solved, in that present machines can read books to the blind. It is more difficult for the machine to decide which pattern of words will carry the intended meaning. Most articles on this topic stress the importance of output to blind operators, but there are a range of uses in real-time situations, where an operator can assimilate speech without being distracted from the scene before him.

7.7.15 Speech recognition, direct interaction between the voice of the operator and the electronic system is more difficult. Progress here would have great impact on telephone systems, but this, as with most examples, does involve the recognition of <u>any</u> voice. The gains from a successful development are large, not least would be in security systems. Speech input is three times as fast as professional typing and can be performed non-locally ie while the operator is moving or is remote. The subject is so important that it is certain rapid progress will be made.

7.8 ELECTRONIC MATERIALS

7.8.1. For the next decade perhaps, silicon is likely to continue to hold its pre-eminent position as a material in the electronics industry. But there are many other binary and ternary solids which are candidates for development and exploitation eg GaAs, GaAlAs, Zns.

7.8.2. Naturally, developments in the field of data acquisition and handling also rely on progress in other aspects of electronic materials science eg fibre optics, advanced lithography and large area displays. Other challenges to the materials technologists will include the integration of electronic and opto-electronic devices on the same chip and the use of molecular systems to transport excitation between systems currently employed in integrated circuits. Theoretical studies will be required to help gain a better understanding of optical and charge transport effects on small time and distance scales.

7.8.3. The two areas discussed below should serve to illustrate the need for more research on electronic materials. There is already considerable interest in the first of the topics selected and commercial devices are likely to emerge during the next decade. The second is rather more speculative and discusses some facets of micro-electronics to which many (untapped) inorganic extended solids and organic molecular chemistry could make a decisive contribution.

7.8.4. Quantum Well and Low Dimensional Inorganic Structures

7.8.5. Recent advances in semi-conductor materials, growth, and assessment techniques have made possible the creation of ultra-thin multilayer structures with a periodicity of the order of a few nanometres. In these structures the composition or the electrical doping may be varied to produce heterojunctions, quantum wells, and superlattices in which quantum effects determine the electronic energy levels. These quantum well (QW) structures exhibit new effects not present in bulk solids, and combinations of known properties, which offer a wide range of novel device possibilities. These developments may be regarded as a new branch of research in both basic physics and device physics or solid state electronics. Device applications will include both `photonics´ such as lasers and detectors whose wavelength may be selected during growth for optimum performance, and a wide range of electronic devices. Industrial applications will require further investment in sophisticated growth techniques such as molecular beam epitaxy (MBE) and metal-organic chemical vapour deposition (MOVCD).

7.8.6. Molecular Electronics

7.8.7 The most consistent features of microelectronic circuit construction over the last 30 years are the smaller and smaller dimensions of the individual components and the even higher density of packing on the silicon crystal surface. This was brought about largely by improvements in the spatial resolution attainable by lithography (from ultraviolet to x-ray to electron beam), which itself depended on advances in the organic photochemistry of photoresist materials. A point has now been reached where only a modest further diminution in the size of circuit components would bring us to the scale of individual molecules. There is no certainty that this will happen and at present it is not even possible to predict by what means this might be achieved. The problem of stability of 'organic devices will, in general, be severe. There is a need therefore to explore novel types of both organic and inorganic microlithographic resists or new types of organic frameworks (rich in C=N, C-C bonds) which are stable to high temperatures. It could possibly be realised by advances in semiconductor technology which in the research phase is already dealing with dimensions on the 10 nm scale.

7.8.8 An alternative approach would be to exploit the inherent small size of organic molecules rather than by the direct fabrication of small structures in large, expensive and complicated machines. That is, the fabrication methods used in conventional microelectronics are with the exception of etching in lithography, chemically non-specific and look crude as structure size approaches molecular dimensions. Self assembly is the fabrication of unique three dimensional structures which are determined by the shapes and charge distribution of the units (molecules) from which they are built and not by the method used to assemble them. Starting from the hypothesis of self assembly in molecular aggregates it is possible to identify a number of specific research objectives in the field of microelectronics to which synthetic molecular chemistry can contribute and for which a multi-disciplinary approach is required. Initially, these lie within the context of present day silicon MOS technology but might in the distant future lead to molecular circuit elements, three dimensional memories and molecular arrays acting as concurrent as opposed to sequential processor networks. In this connection, several features of biological information processing systems look attractive when compared to conventional solid state circuits; these considerations have led to the concept of bioelectronics. There are, however, great practical difficulties in interfacing biological systems and semiconductor surfaces but in the electrochemical electrode area, for example, peptides and proteins can be incorporated in derivatized electrode surfaces. System damage can occur for a variety of reasons and fault tolerant designs requiring new theoretical principles will be necessary. It is more likely that we shall learn from biology about the physical principles of organisation and assembly rather than using biological molecules themselves in devices.

7.8.9 An alternative and broader definition of Molecular Electronics is the systematic exploitation of molecular (including macromolecular) materials in the field of electronics. The SERC has recognised the importance of co-ordinating and stimulating research activities in this field by establishing a special advisory group linked to both the Science and Engineering Boards of the Council.

7.8.10 Research on molecular electronics is of very wide scope and is inevitably interdisciplinary. It has three main aspects: the design and preparation of new molecular materials, the study and optimization of applicable properties, and the development of practical devices. These aspects are not independent, and one characteristic feature of research in this area is the synthesis of hybrid materials which combine the virtues and minimize the faults of the parent materials.

Materials and properties of particular interest include:

- Liquid crystals, less for their now familiar use in displays than for their potential use in switching and memory elements

- Langmuir-Blodgett films deposited from solution onto a solid substrate; with the natural molecular orientation within each monolayer, the control over molecular architecture, and the precise definition of thickness, these films are valuable model systems for fundamental research and their potential is being explored in applied areas such as ferroelectricity, electro-optics, lithography, etc.

- Polymeric photoconductors and semiconductors which can be doped to increase their response, yielding photocopying systems and novel storage battery materials which need contain no metal.

- Organic metals and superconductors, of potential value in connecting active materials and conventional semiconducting substrates.

- Materials which react in light or electron beams and permit microlithography with features approaching molecular dimensions.

- Photochromic and electrochromic materials which change colour rapidly to produce stable high-density information storage systems, easily read and conveniently erasable.

- Pyroelectric and piezoelectric materials useful in detectors and transducers such as the electret microphone.

- Biological molecules which can be used as sensors when immobilized on a semiconductor substrate which monitors their specific response to a target species.

- Electro-optic nonlinear optical materials which combine high response and stability useful in integrated optics and opto-electronics.

- Volatile organometallic species which can be decomposed thermally or optically in the vapour to deposit epitaxial layers of inorganic semiconductors having a well-defined composition and thickness.

7.9. ENERGY, MATERIALS AND MANUFACTURE

7.9.1 ENERGY

7.9.2 It could be said with confidence that the late 1970s were the years of energy research. The vital importance of energy has always been widely recognised and the two oil price shocks of 1974 and 1979 led all industrialised countries to consider in near panic a great number of new possibilities for energy supply and use. As an illustration, of the effort devoted then, the US energy R & D budget more than doubled in real terms from 1973 to 1980. Clearly a great deal of ground was covered. New options for energy supply which were studied varied from solar-power satellites, ocean thermal energy conversion equipment and coal and gas liquefaction processes to photovoltaic hydrogen production in biological systems and growing catch crops for energy production. Energy use measures included novel heat pumps, better insulation and heat recovery systems, electric energy management for buildings and vehicles etc.

7.9.3 For a long time to come the most important sources of energy will be fossil fuels, notably coal, oil and natural gas. To gain these fuels economically, transport them economically, process them economically and utilise them economically will be a continuing challenge and an area that continually will depend on improving technologies. Moreover, it may well be expected that constraints in all these areas will be increasing due to public opinion being aroused on matters like the safety of those working in the North Sea, in coal mines, in power stations, etc, the environmental impact of gaining fuels (oil pollution, coal spoil heaps), environmental effects of long distance transport and its dangers (liquid natural gas) and, above all, the environmental effect of burning fuels (soot, acid rain, CO2). The combined effect of these will require a continual advance in the relevant technologies and great benefits to those who are first in the field with a relevant technology.

7.10 Mining and Extraction

7.10.1 The very first step must be the location of such resources. There have been rapid advances in geophysical work, notably in the processing of records in seismic work, but there is still an enormous amount of black art in geophysical interpretation, particularly as regards the identification of the economic potential of any oil reservoirs discovered. Considerable advances would seem possible in geophysics, perhaps through the better utilisation of the computer-man interface in geophysical interpretation and through better modelling and better understanding of the flow of liquids and gases in oil reservoirs. The best test of geophysical predictions is of course drilling. Improvements in drilling methods, and especially the lowering of the cost of deep drilling will be an important advance and an understanding of the scientific factors going into the economy of deep drilling will be important. Perhaps a particular item of relevance is the hypothesis, hotly contested, and there are very considerable amounts of natural gas low down. Again, this is a scientific question that could have, one way or another, significant economic consequences.

7.10.2. Next, come advances in the economic exploitation of oil and coal reserves. On the oil side, higher recovery factors through tertiary recovery of oil would have enormous economic importance, but the scientific questions of how to approach this problem are still ~~very ill~~ poorly understood and whether it is a question of using surfactants, or perhaps bacteria, to assist in the extraction of oil beyond the modest percentage now recoverable, there are great gains to be made. Relevant research areas relate to reservoir engineering, particularly fluid mechanics of mixed phase and colloidal systems, and mathematical modelling. So far the subject has proved very recalcitrant, but there is no reason for not pursuing it energetically. Again, interesting questions arise when oil in particular is found in inconvenient and awkward locations, such as under the sea, under the Polar ice, etc. Much of the knowledge gained in the North Sea now resides in North America, but enough of the experience gained exists in the UK to make British companies strong competitors for the exploitation of under-sea resources elsewhere. These are areas which cry out for increasing automation, perhaps particularly in ~~the~~ inspection, maintenance and repair~~s~~, where greater capabilities of remotely operated vehicles would reduce the number of occasions divers have to be called upon with all the attendants costs and risks. This again is an area where attention to scientific questions of metallurgy, of experimental phsychology, of the man-machine interface, and of mechancial engineering, could lead to significant and economically very worthwhile advances. It should be mentioned here that coal beds under the ocean are not uncommon, yet their economic exploitation still seems to be a fair way off.

7.10.3 Mining techniques especially at great depth will be developed using remote handling techniques, robotics will be a requirement. No doubt further attempts will be made at underground gasification, which will require advances in the science of mixed phase gasification and the kinetics of heterogenous reactions. Such fields are also relevant to the gasification and pyrolysis of coal to produce chemical products, the chemistry is well understood, but the catalytic conversion of alcohols of motor fuels using zeolyte catalysts is important, and further research is needed on the catalytic conversion of coal products. New mining techniques for coal are required. If a solvent could be found to cope with coal's low solubility, the solution could be pumped to the surface or piped directly to underground power stations.

7.10.4 Coal technology is only developing slowly. The transportation and burning of water-based coal micro-suspensions is being pioneered in Sweden (and coal/oil suspensions elsehwere); relevant science areas are colloid chemistry and non-Newtonian fluids. This technology is environmentally attractive because sulphites can be floated off as a pre-stage to fluidised bed combustion, an alternative to sulphur dioxide scrubbing of combustion products. The technology which also eliminates dust omission, is dependent on the chemistry and physics of grinding fine powders.

7.11 Transportation Fuel Science

7.11.1 In the transport field the most important areas would seem to lie in avoiding the environmental risks of oil transport, in making the transport of liquified natural gas less hazardous (that applies to storage on land too) and in making environmentally acceptable port facilities for the large scale movement of coal around the world, a movement that is almost bound to increase sharply in the next twenty five years or so. In the fuel processing area the biggest hopes would seem to lie in truly economic processing of coal. Coal liquefaction is well understood in principle, but apparently at the moment is useful only where it is strategically desirable to do so and coal is exceptionally cheap (South Africa). Hard-headed assessments are required in this area, but the future utilisation of coal in liquid and gaseous form must not be lost sight of.

7.11.2 This leads directly to questions of environmental acceptability. Coal gaining as well as coal-liquefaction and gasification certainly have a poor reputation, deserved or undeserved, for environmental acceptability. Scientific work that could lead to significant improvements in this would be very worthwhile. Though the gaining of oil and natural gas can already be made environmentally very acceptable at a most overwhelming price, initial drilling and proving of resources causes considerable community reactions and there may be scope for improving this aspect.

7.11.3 An immense area of promising science lies in improving the environmental acceptability of the burning of fuels. The centre of present concern relates to motor vehicles and their emissions, particularly of nitrous oxides and of hydro-carbons that are unburnt, or only partially burnt. Wide areas of combustion science, of catalytic effects, of atmospheric chemistry are involved so that what is attacked, possibly expensively, is at least known to be that which affects the environment, a condition far from fulfilled at present. In many forms of burning, not just in motor vehicles but in power stations and industrial plant, considerable progress should be feasible at least once one knew what one was trying to avoid. The striving in the interests of fuel efficiency for higher and higher combustion temperatures has landed us with a problem relating to nitrous oxides. The utilisation of coals with a higher sulphur content (and of oils also) is inhibited by the emissions, whose economic control still poses considerable scientific questions of great worldwide interest. Altogether the use of fuels that on other grounds might be regarded as undesirable (eg corrosion in boilers due to salt inclusions in coal) is again a sizeable area in which advances could be of considerable benefit.

7.12 Nuclear

7.12.1 The technology of thermal reactors is now mature. Since large PWR's are inappropriate for the electricity grid systems in developing countries, the smaller and well-proven British Magnox system would be particularly suitable for export to such countries. However, problems associated with the processing of spent fuel, safe storage of radioactive waste, and security of plutonium would need to be overcome. World uranium supplies are adequate for present thermal reactors well into the next century, but such reactors make inefficient use of uranium, and the next stage in world development of nuclear power is the fast reactor. Lead times in the construction of such complex plants are very long and considerable demands are placed on the technology. More work is needed therefore in the fields of chemistry of the fuel cycle, including the thorium cycle, safety and fracture mechanics, hazard analysis, control of complex interacting systems and ergonomics.

7.12.2 We have referred early to more long term and costly scenarios for the development of fusion technology. Within those scenarios, scientific areas which require a greater understanding are the chemistry, physics and fluid mechanics of plasma and heat transfer where electro mechanical interactions are taking place. Laser fusion also requires further research.

7.13 Electricity Generation, Fuel Cells and Batteries

7.13.1 There will be moves to generate electricity with conversion efficiencies of 50% or more, and in terms of end use, electricity will be used more and more. The underlying sciences are non-equilibrium thermodynamics and rate processes, and magneto-hydrodynamics, complex thermodynamic cycles using a variety of working fluids. So far as the end use of electricity is concerned, dilute plasma properties, induction, microwave and rf applications of electricity are relevant. Technologies related to end-use concern furnace and boiler design and control, and design and control of traction in electric motors.

7.13.2 Technological developments are expanding the range of fuel cells available into the megawatt power range at one extreme and a low voltage source suitable for electrolysis at the other. Work on solid state lithium batteries with oxide cathodes is being carried out in the UK. Batteries and fuel cells will become much more used and sophisticated based on developments in electrochemical engineering and electrochemical kinetics. Much of this work requires the use of high temperature resistant materials both ceramic and metallic.

7.13.3 The approach of the chemist could be valuable in the search for better batteries eg the exploitation of catalysis to convert low value energy into useful amounts of storable energy and the production of new forms of miniaturised soild electrolytes. Slow progress is being made in creating a catalyst for the photo-chemical decomposition of water into hydrogen and oxygen - a development with a potentially wide range of applications and an unlimited market. One of the critical problems being tackled in the UK is the science of the interfaces between semi-conductors and solutions.

7.13.4 An air cathode is needed in every fuel cell to provide oxygen. In order to dissolve oxygen at the rate commensurate with the fuel supply, porous electrodes are used, but there are limitations imposed by high current densities and overvoltages. The rate of gas dissolution in the electrolytes could be enhanced by using a rotating pool of electrolyte. Preliminary experiments have been carried out and if these confirm the theoretical predictions, immense new market opportunities for fuel cells will be opened up for efficient, quiet motors and in chemical manufacture.

7.14 Renewable Resources, Storage and Efficiency

7.14.1 Geophysical processes (solar, geothermal, marine energy gradients, etc) are a source of largely untapped energy and their exploitation will provide an area for a fruitful combination of physics and engineering. Wind power technology is advancing and could be used as a top-up to other forms of electricity supply. The underpinning areas of science are aerodynamics of energy conversion, aerodynamics of complex arrays of wind generators, energy conversion using low heat devices, and associated electrical engineering involving synchronous interaction with the grid and operation of mixed systems of generators eg wind and diesel generators perhaps with some solar electric. Other areas with potential are solar-photovoltaic conversion, passive solar construction in building, and in the very long term photosynthesis.

7.14.2 Energy storage techniques worth pursuing include reversible heat storing materials (latent heat), design of large flywheels, ie rotating machines, cryogenics and superconducting magnets.

7.14.3 The opportunities for energy conservation are still large. We have already referred to the process of combustion which is not fully understood and improved science leading to gains in combustion efficiency is of crucial importance in power generation and propulsion. Combined heat and power must be able to achieve a better overall efficiency than the 30% currently achieved. If a process could be found for recovering and harnessing low grade heat eg that discharged via cooling towers, it would be a valuable and marketable commodity. A role might be envisaged in this for heat pump cycles, or perhaps chemical conversion or storage. Other possibilities for increasing efficiency of energy utilisation could stem from studies of working fluids in heat engines, control of electricity use with efficiency in mind, electric traction, and microprocessor control of engine combustion.

7.15 MATERIALS

7.15.1 We attach great importance to research into the properties of materials since the area provides the fundamental underpinning science for advances across a broad technological front and in many other scientific areas. The prime areas with potential economic significance are

a. materials science

b. catalysis and chemical reactivity

c. intensification science

7.15.2. The scope for new developments in "pure" chemistry is limited, and academic chemists should now work with other disciplines. Organic chemistry has moved on to make significant advances in the subtlety of understanding of the physical (particularly kinetics) and theoretical aspects of organic chemistry using powerful computers. For the invention of new effect chemicals a vital understanding of intermolecular forces (dipole interactions, hydrogen bands, etc) is required but the UK has fallen behind internationally in this area. Those at the frontiers of discovery in organic chemistry are working at disciplinary interfaces and combine computing with large instrumentation to predict and analyse reaction products. Computer-aided synthesis is at a primitive stage and few routes have yet emerged in practice. Directions in synthetic chemistry are leading to more efficient syntheses. New techiques in chiral synthesis, sometimes using fermentation, and the use of transition metals in organo-metallic catalysts are providing reaction control and selectivity that are of great importance. Polymeric reagents are of growing importance. Chiral synthesis has important conceptual implications - the use of chiral "building blocks" in the synthesis of complex molecules, the potential replacement of the conventional synthetic chemist by the synthetic biochemist, and the regeneration of fermentation technology.

7.15.3 MATERIALS SCIENCE

8.15.4 In the primary role, it is the intrinsic physical and chemical properties that dictate which material is used for a specific function and therefore the choice is limited. There should therefore be a move away from concentration on properties of materials related to structure towards studying how to make the end structure in the optimum way. We believe that the following areas in research and use of materials will lead to prospective technological applications.

a. use of inorganic elements that are abundant

b. derivatisation of surface by chemical modification at the monolayer level

c. ion-implantation and intercalation techniques

d. chemically-linked composites

e. tailor-making polymers, organo-inorganic and organo-matallic compounds

f. broaden the use of metals

g. engineer organic crystals/thin films

7.15.5 Polymers

7.15.6 It is not considered that conventional high volume polymers such as polythylene, polyvinylchloride or polystyrene will be challenged by developments in the fabrication of polymers will be sought to substitute for metals. Organic synthetic chemistry will be important in the search for new structures of crystallinity, molecular weight, and molecular orientation to improve temperature stability and mechnical strength in polymers. Tailor-making will be play a major role in production of engineering and high performance polymers. High temperature plastics for application in aerospace, electronics, medical fields is an area with considerable potential, as is the manufacture of polymer membranes for the separation of gases eg carbon dioxide/methane or nitrogen and oxygen.

7.15.7 Polymer Composites

7.15.8 A promising approach to increasing the versatility and applications of polymers is to incorporate an inorganic phase into the polymer to produce matrix and interface structures with properties of stiffness. Compounds produced by such processes range from carbon/glass fibre reinforced thermosets, mineral filled thermoplastics to plastic-metal laminates. Fibre-based thermoplastic composites particularly might offer new materials to industry with major improvements in properties. New technologies will be required for moulding such materials. One such approach is by means of mould-mapping using computer aided techniques. As much as 70 per cent of fibre has been incorporated into polyurethanes and other polymers which has allowed composite plastics to challenge steel components in some markets.

7.15.9 The science of long-fibre reinforced thermoplastics has yet to be overcome. Such materials are of particular importance in the aerospace market which requires high strength/weight ratio in materials. Opportunities exist for continuous collimated systems. The main technical obstacles currently are:

a. to overcome the high viscosity of the polymer to achieve a degree of wetting that will share loads evenly over all fibres;

b. to improve the compressive strength and prevent degradation of properties due to impact or fuel spillage, particularly with epoxy-based composites.

Future development of thermoplastics will depend on improved processing techniques in the following areas

- injection moulding techniques
- reproducibility
- fibres with higher failure strains
- increased glass transition temperature (softening temperature)
- alternative ductile matrices (better interface science is needed at the 5 micron level)
- toughening with metal matrices
- combined thermosets and thermoplastics

7.15.10 It is likely that polymer matrix composites will dominate overmetal matrix and ceramic matrix composites because of cheapness. New polymers are required for high temperature materials. Composites involving platelets are also of interest eg to improve the hermeticity of plastics. Metal/inorganic composites have considerable potential. In such composites, the softness of the metal is overcome by reinforcing it with inorganic fibre. Interesting possibilities are emerging for `cerimets´ which combination of ceramic powder in a metal matrix. Other opportunities will arrive from filling ceramics to generate ferro-magnets. The boundary between metals and organo-metallics is also becoming indistinct, with the possibility of designing ferro-magnetism as well as conductivity into organic materials.

7.15.11 Ceramics

7.15.12 There has been a significant increase in ceramics research world-wide in recent years. This has been stimulated by the search particularly in Japan for heat resistant, high strength structural members to replace traditional materials such as metals. The new ceramic materials currently under study are based largely on aluminium, magnesium, silicon and ziroconium oxides and the nitrides and carbides of silicon. As in the case of metals, it is expected that new ceramic materials will be generated through the technique of ion implantation. Basic chemical techniques involve setting and sintering such inorganic material to produce grain and void structures with the properties of processability and high strength.

7.15.13 But major changes are anticipated in the processing technologyfor ceramics, which is currently crude, reproducible and expensibe. Better control of particle packing and sintering is a prerequisite. The need for improvement has been stimulated by engine manufacturers who require higher temperature materials beyond superalloys and by the need for increased strength. Electro-osmosis, plasma and laser deposition methods are all being brought to bear on powder preparation for ceramic forming. Sintering is currently a high temperature energy intensive process producing high-perosity products. A lower temperature process is required which may be achieved by using cable compounds incorporating ceramic materials.

7.15.14 Areas where new ceramic materials find applications are:

Electronics - intergrated circuits, electronic packaging, substrate for film circuits, ferrite core, non-conducting magnets, ceramic capacitors, thermistors, piezo-electric materials.

[Surface science] Materials used are alumina, beryllia, barium

	titanate.
Deposited films [Friction properties]	- fabrication of VLSI circuits, electrical insulation. Materials are mainly of polycrystalline silicon, silicon dioxide, silicon nitrides. Such materials have applications in diffusion, ion implantation, passivation, and protection in microelectronic manufacture.
Heat engines [Ceramic processes]	- gas turbines,diesels, turbochargers. Further research is needed in this area in order to overcome basic problems related to the thermal stability of ceramics.
Cutting tools	Based on silicon nitride and sialon.
Mechanical seals and bearings	- shaft sealing devices, pumps, agitators and other equipment handling fluids - silicon carbide based ceramics.

7.15.15 Non-Polymeric Materials

7.15.16 Considerable research interest has been shown in development of common materials manufactured on a large-scale such as cement. Novel materials such as pore-free hydraulic cements have been developed and further research into cement and other pastes may provide more inorganic `plastics´ with interesting properties.

7.15.17 Amorphous metals

7.15.18 Superplastic metals have been developed, in which grain texture is controlled by introducing foreign materials, as in blow moulding. The controlled structure of amorphous metals which imparts high chemical resistance and magentic proprties, is produced by rapid quenching. Novel surface treatements (eg laser surface melting) are being developed to generate glassy metals which have corrosion resistance. The technique of ion implementation, which is a spin-off from surface spectroscopy will open up the prospects for new materials in both metals and ceramics. Foreign atoms are introduced physically or chemically into the surface. This enables structures to be changed locally rather than in bulk and properties to be modified after fabrication. New industries based on these novel methods of surface treatment (coating, hardening, etc) are emerging. Processing by powder metallurgy is attracting considerable attention, and is bringing metallurgy much closer to plastics technology. Relevant to this area, also, is the study of colloid dispersions in which the continuous phase is a molten metal.

7.17 COLLODIAL AND INTERFACE PHENOMENA

7.17.1 This area is a diverse and multidisciplinary applied field involving physics, chemists, biochemistry, and engineers. The phenomena of colloid and interface states of matter is related to science of condensed matter and the molecular state in general. The structures for progress will come from cross-fertilisation with other fields, and advances stem from the application of theoretical and experimental methods developed for studying molecular systems and bulk matter in general. Opportunities arise for exploitation relate to production of novel surfactants, coal/liquid properties, dispersants, electro-rheological fluids, anti-fouling chemicals.

7.17.2 The manipulation of polymers at interfaces is leading to a greater understanding and control of colloid systems in which the continuous phase, and sometimes the disperse phase, is polymeric. This will impact on development of surface coatings and composite materials, and possibly conducting polymers. An important area concerns high molecular weight, polymeric surfactants, in which the aim of research is to tailor functionality eg crosslinking, coupling agents for fillers in polymer matrix.

7.17.3 Depletion flocculation which is concerned with the complex "state of dispersion" could have important consequences for research in biosystems and "self-assembly" type of structure, as well as for industrial exploitation in relation to dispersion of polymer particles in water rather than in more environmentally undesirable organic solvents. Understanding is needed of rheological changes which occur, most commonly, in otherwise stable dispersion when the concentration and molecular weight is dissolved polymer is varied. Novel room – temperature reactions are required to provide stability for metastable mixtures.

7.17.4 Conducting Materials

7.17.5 New organic polymers have been produced with conductivities approaching that of metallic materials; such materials include polyacetylene, polyparaphenylene, and polysulphurnitride the latter also displays superconductivity. Such materials may find applications in solid state batteries for example in the multi-layer chip industry, antistatic uses, electronagmetic radiation shielding. The range of polymers of this type is being extended, for example, to produce conductive blends.

7.17.6 Materials that are superconducting at higher temperatures would be useful. In theory, room temperature super-conductors is possible, but liquid hydrogen temperature will probably be the effective limit in practice. Inorganic materials may provide a more fruitful area for investigation. A group of compounds basedon metallo-macrocycle substances offers another promising range of conductors with interesting electronic properties.

7.17.7 Catalysis and Chemical Reactivity

7.17.8 We consider that important opportunities will flow from development of a greater understanding of factors affecting and mediating chemical change, of the use of new materials for controlling chemical reactivity and for producing new ways of chemical synthesis. The major fields of interest at present in this area are.

a. Heterogenous catalysts

b. Metal/Organometallic catalysts (either homogeneous or anchored catalysts)

c. Surface chemistry including light sensitive materials and electrocatalysis

7.17.9 Heterogenous Catalysts

7.17.10 Heterogenous catalysts, for example, zeolites are complex crystalline silicate/aluminate compounds synthesised in such a way as to exhibit molecular sieves properties which permit shape and size selective chemical reactions to take place. Such catalysts have been increasingly used, in recent years, in major processes in the chemical industry, for example, reforming, cracking, polymerisation etc. A challenge to zeolites recently has come from pillared clays, which can perform some of the function of zeolites, and also have further chemical uses. The transition elements and their compounds which have been "tuned" to specific properties are of increasing interest as substitute catalysts for the more expensive previously used noble metal catalysts. Further catalyst research might also have spin-off in tackling some environmental problems.

7.17.11 Metal/Organo Metallic Catalysts

7.17.12 The chemistry of such homogeneous catalysts is based on clusters and other supported metal/metal oxide in which the catalyst-support interaction is significant in order to obtain high selectivity. Such catalysts have already found important industrial applications, for example, in the production of polyester and acetic acid. Interest has developed recently in certain organo metallic catalysts to increase the reactivity in a number of relatively inert compounds such as carbon dioxide, methane, nitrogen, etc of which there is a relative abundance. The key to such reactivity is the breaking of the strong carbon-hydrogen bond. In this context, homogenous catalysts such as organorhodium and organoiridium have been found to have interesting properties. Research in stereoselective catalysis also presents the possibility of synthesis of important biological compounds for use in medicine.

7.17.13 Surface Chemistry

7.14.14 Research in surface chemistry is basic to increasing understanding of chemical reactivity; the chemistry of atoms at surfaces is fundamentally different from when they are in the gaseous or liquid phase. A greater understanding of the chemistry of the solid/liquid interface is also required. Advances in surface chemistry will be of crucial importance to developments in micro-electronics, catalysis, electrochemistry, separations, colloid phenomena, surface analysis, and surface spectroscopy. At the present time, there is a lack of versatile, discriminating probes. A major problem is the lack of ability to identify and characterize the transitor species that are involved in catalysis on solid surfaces when only a few per cent of the surface is participating in the conversions. Spectroscopic probes tend to select those species that are the most dominant on the surface: often these are spectator species.

7.17.15 Membrane chemistry is an area which presents considerable opportunities. Multiphase synthesis using the controlled chemistry that takes place within a membrane is a promising area currently being driven by chemists' inquisitiveness. Membrane chemistry is attractive as a means of avoiding bulk phase reactions. Preferred physical alignment of molecules can be achieved at the membrane interface. It may well be possible to separate specific ions, on the basis of difference in size, eg electro-winning of metals from concentrated solution. Related to this is the adoption of solid membrane technology to water purification plants; liquid membrane technology will also have impact on such uses.

7.17.16 Radiation Sensitive Materials

7.17.17 Conversion of light to electrical energy has been the objective of research for a number of years. By the use of suitably modified semi-conductors it has been possible to develop photochemical cells capable of converting solar energy with the same efficiency as photovoltaic cells. Studies on photochemical cells have produced interesting developments in photocatalytic chemistry. When a semi-conductor absorbs light a catalytic oxidation- reduction reaction takes place at the electrode-or membrane-solution interface. Such reactions may have potential for example in the solar driven photoelectrolysis of water to hydrogen and oxygen.

7.17.18 Electrocatalysis

7.17.19 Recent developments in this field have demonstrated that the surfaces of electrodes can be treated chemically in such a manner as to favour one or a few subsequent electrode reactions. Electrocatalysts made by such techniques have been used, for example, to increase energy efficiency in the chloralkali industry in the USA. Such materials might also be used in development of fuel cells for converting chemical fuels to electricity. But other opportunities exist ranging from moulded electronic components to non-cryogenic superconductors. Developments are likely to use polymeric (ionic) conductors and gas or solid phase (in contrast to liquid phase) electrochemistry. More generally, electrochemistry could be the source of new routes to high added-value chemical compounds (eg organics and optically active isioners). This will involve the immobilisation of oxidising and reducing agents or enzymes on electrodes. In the future, these may be made from ceramics or polymeric materials.

7.18 INTENSIFICATION SCIENCE

7.18.1 Molecular Interactions

7.18.2 Certain chemical reactions can be tailor-made by designing molecules to interact in a highly controlled way with other specific molecules. Such interactions could be used, for example, to transport biological molecules through membranes or as a sensor by selectively extracting a compound from solution. Another example is that of metal-ion receptors, which could be used to promote surface adhesion through the design of specific polymers which will combine with metal ions on surfaces. Reversible photoactivation of the receptor mechanism could provide the basis of a gate for metal-ion transport. Activation with a tunable laser might provide the added advantage of Spanial selectivity. In general, the mechanisms of small molecule receptors could be applied to catalysis and to problems such as the removal of small insoluble gas molecules (eg CO or O2) from their immediate surroundings. Redox reactions could be controlled by coating an electrode witha permeable layer whose reactive properties are charge-dependent. Thus the panage of a specific chemical species through the layer could be controlled electrically - another form of ion gate.

[Further paragraphs with following structure:

a. Some typical problems (oxygen, nitrogen from other gases eg, hydrogen or carbon dioxide-products eg isomers)
b. How can this be done?
c. Some typical illustrative examples

Separation
- i. straight chain from branch-chain hydro-carbons
- ii. unsaturated from saturated hydrocarbone
- iii. permanent gases (one from the other).]

7.19. MANUFACTURING TECHNOLOGY

[Include aspects of biotechnology using unconventional routes eg separation of inorganic materials (Fe3 04) for magnetic tape using magneto-tactic bacteria]

7.19.1. In manufacturing technology we believe that many major issues for the future will be concerned more with problems stemming from the application of new science and technology rather than the technology <u>per se.</u> Such issues are related to aspects of social change and attitudes to work which we have discussed earlier. The long-range social trend affecting the field of manufacturing today is that towards a post-industrial society. This trend is in turn producing important changes in attitudes towards manufacturing.

Three trends are visible -

a. increasing reluctance to seek employment in manufacturing

b. greater effort to improve the work environment and job satisfaction in manufacturing

c. more active role by Governments to improve working conditions.

The percentage of the workforce employed in manufacturing declined from 30% in 1947to 22% in 1978. It has been forecast by the Rand Corporation that by the turn of the century only about 2% of the workforce in the USA would be engaged in manufacturing. Nevertheless, in all the industrialised countries of the world, there is, on average, an increasing shortage of willing, capable manufacturing workers as a result of this trend.

7.19.2. The migration of labour force into services puts a direct social pressure on the manufacturing industry to increase its productivity at a rate sufficient to more than compensate for the shrinkage in its labour force. Improvement in manufacturing productivity occurs primarily from an increase in manufacturing technology as the following figures indicate -

Contribution to manufacturing productivity increases are -

Labour	Capital	Technology
14%	27%	59%

Ref: Morrison D L & McKea R
1978 Technology for Improved Productivity

7.19.3. In industrialised countries throughout the world today, there is a pronounced trend of increasing efforts in development and implementation of advanced manufacturing technology. This technology includes such developments as new types of machining processes, for example laser machining, new types of materials such as composites, and new ways of organising manufacturing such as cellular manufacturing. However, by far the most significant and important type of advanced manufacturing technology being developed and implemented today is computer integrated design and manufacture. The objective of such advanced manufacturing technology are:

a. higher quality products straight from the "drawing board;"

b. reduced development time;

c. reduced testing time;

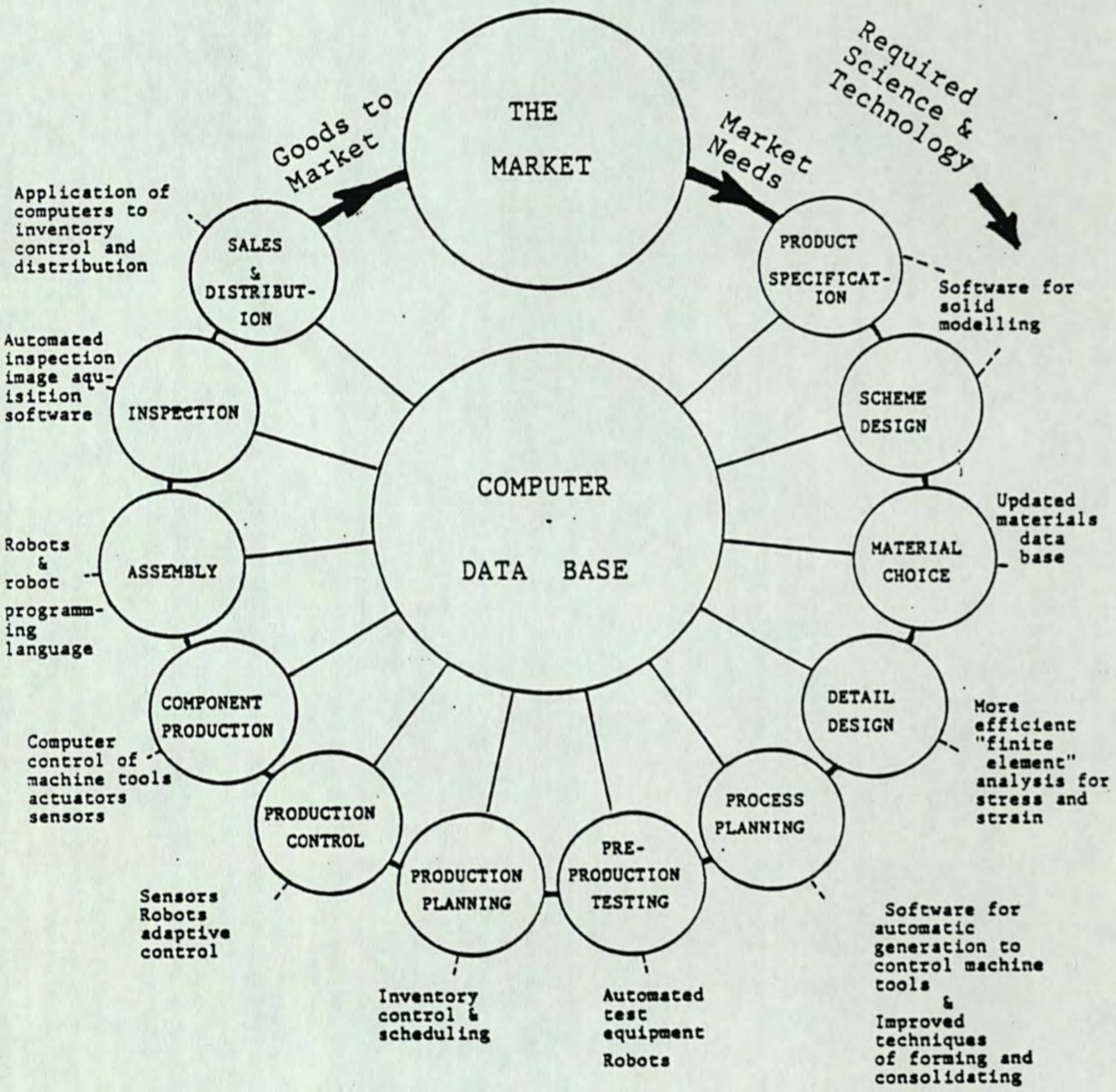
d. reduced machine tool non-productive time;

7.20 COMPUTER INTEGRATED MANUFACTURING(CIM)

7.20.1 Manufacturing engineering in the United Kingdom will increasingly be required to consider the totality of the process from raw material to product in much the same way as chemical engineering does at the present time. The traditional compartmentalisation between design and it´s methodology, production technology, quality control, and the man-machine interface will be broken down and transformed into an integrated system. Such integrations will be made possible by co-ordination of all aspects of the manufacturing system by extensive use of computerised database shared across many functions elaborate diagram. A flexibly automated factory will use computers in virtually all aspects of manufacturing, integrating production functions with planning and conrol functions. The application of a flexible automation system may well extend beyond the site of production to co-ordinate with sales and even the retail point. The designer will generate the data base which will define the component. this data base can be used with finite element analysis software to determine the stresses, strains and deformations. Solid modelling techniques will be used to examine clearances and the stylistic design. The design of press tools can be automatically generated from the data base. The programs for control of machine tools in the manufacturing process will also be automatically generated [elaborate on basis of diagram]. From this design data base and the market requirements we shall generate inventory control and shop floor scheduling. The manufacturing processes in turn will be automated by robotic tool changing on machines, automated controlled storage and retrieval systems for components, and automated inspection of the finished product by robot.

7.20.2 Information and Sensors Technology

INTEGRATED DESIGN AND MANUFACTURING



7.20.3. The rapid increase in computing power cannot be exploited effectively if it is not matched by a corresponding improvement in the quality of the input data; especially in the field of automatic process monitoring control. There is an apparent lack of information on sensor technology and an inter-disciplinary approach is needed. A major area requiring attention in sensor research is concerned with the development of materials to make them cheaper, more robust and more capable of working in hostile environments for long periods without servicing. Much of the basic science exists, it is the translation into hardware and useable technology which is mainly required.

Areas of science and technology which are of importance to the development of integrated design and manufacturing systems are -

1. Software for solid modelling
2. Object recognition and image acquisition
3. Management of large data bases
4. Actuators
5. Sensors

7.20.4 Fabrication Technology

7.20.5. Fundamental to advances in fabrication technology are developments in the science of materials. More research is needed into the application of computer techniques in assisting in the characterisation and behaviour production of materials, in the selection of suitable materials for fabrication, and in the development of new fabrication processes. The United Kingdom has been particularly slow at introducing even prototypes of new products using traditional processes and insufficient interest is paid in new fabrication technologies such as near net shape forming, powder metallurgy, melt spinning, electroforming, conforming, precision forming. A subset of fabrication technology is that concerned with marine technology.

7.20.6 The whole area of marine technology is a priority one for R & D and commercial exploitation. Considerable fine-tuning is required in current research areas and the following may be identified as areas with significant potential.

a. Ocean characteristics in relation particularly to the needs of shipping, offshore resource exploitation and fishing industries

b. Structural integrity analysis in relation to sea and ocean engineered structures

c. Drilling technology and sub-sea systems

d. General data manipulation techniques

e. The use of new materials

f. Acquisition of more basic data for improving the prospects for mariculture and increasing the potential of alternative energy sources

g. Production engineering associated with the commercial exploitation of the results of current and future research

h. Opportunities offered for commercial spin-off by the solution of environmental problems and the need to respond to legislation

i. Improvement of the cost-effectiveness of ocean systems.

7.20.7 Surface Technology

7.20.8. Allied to materials science, surface technologies are seen as an important area of interest, particularly problems related to corrosion and the need for very low drag. Surface technology developments should find particularly promising markets in the aerospace, pipeline, marine, catalyst and catalytic system technology, and packaging industries, thus embracing a wide range of technology level from the high to the low end.

7.20.9 Space Sciences

7.20.10 In space science, the initial emphasis on propulsion systems and satellite launching gave way in the first instance to the study of the near planetary system but now, with the introduction of the space shuttle and space laboratories, the emphasis is shifting again, this time to the exploration of physical and biological phenomena in a zero-gravity environment. Gravity influences many physical and chemical processes and often induces effects, such as convection and turbulence, which disrupt the objectives of the study. Under the zero-gravity conditions available in space these effects can be eluminated. Zero-gravity environment also permits the manipulation of highly corrosive substances without the use of containers and the production of defect-free crystals. The proposed German space laboratory programe exemplifies the breadth of interest in the utilisation of space conditions. The programme covers interface and transport phenomena (convection, thermal diffusion and conductivity, surface phenomena, dynamics of droplets and bubbles, combustion technology), metals and composites (solidification fronts, separation mechanisms, stability of dispersions, diffusion, metallurgy, alloys, foam metals), crystals (striations, mosaics, tectics, solution and gas-zone, protein crystals), physical chemistry and process technology (equations of state, thermal capacity, nucleation, electrolysis, corrosion, separation and mixing, viscosity, reaction enthalpies, etc), and the separation and behaviour of biological organisms..

7.21. NATURAL PROCESSES

7.21.1. The broad field of biological sciences is a buoyant one and it is widely accepted that it is a promising area of science. However, the areas of science are diverging so rapidly that it is not easy to describe briefly the scientific opportunities. The boundaries between disciplines in the biological sciences are becoming obscured since particular fundamental advances have had relevance to a range of scientific fields. The next twenty years are likely to see massive worldwide effort to apply the new techniques of molecular and cell biology to many important but poorly understood life processes. The era of molecular biology is just beginning, but, while there has already been an explosion in understanding natural processes themselves, their interaction with economic forces is not yet discernable. In describing some of the promising areas of research, we have found it useful to consider the biological sciences in a hierarchical way though the divisions made are somewhat arbitrary.

7.21.2 The broad areas of scientific progress relating to natural processes are likely to find application in

a. Medical science and technology
b. Plant and animal sciences
c. Biotechnological processes

7.22. MEDICAL SCIENCE AND TECHNOLOGY

7.22.1. Definition of Life Processes at the Molecular and Chemical Level is the scientific base of the current approach to understanding natural processes.

7.22.2 Molecular and Cell Biology

7.22.3 In the last few years, molecular biology has developed to become much more than the study of elementary genetic structures and mechanisms and even more than a means for practical manufacture of pharmaceutical and other substances. Its impact on plant and animal biology is revolutionising our understanding of cellular mechanisms including cancer, hormone action, immune recognition, and the performance of agricultural crops; it promises to unravel the long standing mystery of the mechanism of development (how a seed or fertilised egg develops into the fully differentiated seedling or embryo), and it is not unlikely that it will open new approaches by which major advances will be made in the understanding of brain function.

7.22.4 The ability to rapidly clone and sequence cDNA and genomic DNA when applied to receptors for hormones, neurotransmitters and other agents (eg low density lipoprotein) - is leading to information about the structures which cells use to recognise signals and other agents at their surfaces. This will point to the reasons for genetic predispositions to disease such as atherosclerosis and suggest possibilities for the design of new generations of drugs.

7.22.5 Similar approaches have revealed homologies between growth factors, their receptors, and the so-called oncogenes - which show how natural cellular growth mechanisms work and how they are modified in cancer. Such insights take us right into the central mechanisms by which tissue cells process the information they receive and how they respond to it, with considerable implications for understanding and dealing with dysfunctions in disease.

7.22.6 Studies of the receptors of immune cells, are revealing the nature of the elementary structures through which foreign materials are recognised by the body. This will enhance our understanding of how the subseqent natural responses develop and are orchestrated, and hence to means by which beneficial modulation may be achieved - for example enhancement of appropriate responses to help the suppression of infection, and attenuation of inappropriate responses as in allergies, transplant rejection, or to immune diseases.

7.22.7 Greater understanding of the structure of the genetic material in developing organisms is leading to important understanding such as

i. the sequences responsible for the switching on and off of genes to express new cell functions

ii. the nature of some of the genes responsible for overall pattern specification of the organism (eg the so-caled homeobox sequences).

Thus we will begin to understand the reasons for the wide ranges of inherited diseases as well as the origins of birth defects of many types.

7.22.8 Investigations of the sort described above, are proceeding on both animals and plants but most progress is of course being made with the former since the concentration of effort is there. However, the applications to plants will lead to the development of greatly improved agricultural crops - expressing, for example, improved oils, cereals, proteins, and secondary metabolites - as well as having improved growth characteristics.

7.23 Protein Chemistry

7.23.2 The size, complexity and instability of proteins have previously constituted a barrier to the full utilisation of their enzymic and pharmacological properties but this has been transformed by the development of a number of complementary techniques for the isolation, analysis and synthesis of proteins. Amino acid sequences can now be determined from very small quantities of proteins. Other techniques such as knowledge based computation, radio immunoassay, NMR, neutron diffraction and scattering are proving useful in elucidating complex molecular structures.

7.23.3 The ability to transfer genetic information into microbial cells to code for the production of specific proteins, offers the prospect of large scale preparation of commercially valuable molecules. Cells can be manipulated to produce desired proteins in greater quantities than occurs naturally and the products are already proving valuable in basic experimental biochemistry (for example adequate amounts of cell-receptors are beginning to be made available and this will greatly facilitate the study of receptor function and ligand binding) and for commercial exploitation (for example human insulin). Techniques are being developed to use mammalian cells particularly to secrete or modify natural polpeptides. in five years time techniques will be available to permit genetic manipulation of a large range of animal and plant cells.

7.23.4 The identification of the proteins responsible for important cell functions has been enhanced both by the use of techniques to identify subtle genetic differences between cells (subtraction hybridisation), and by using the unique selection property of antibodies to purify a particular protein.

7.23.5 Perhaps the most powerful development influencing protein chemistry has been the invention of new methods for chemically synthesising genes, using step-wise polymerisation of the component nucleotide bases in the correct sequence to code for a specific protein. Alongside such techniques as site-directed mutagenesis, gene synthesis and cloning technology open the way to what is now called protein engineering. This subject is in its infancy but offers the prospect of making or modifying proteins to order. It will also enable understanding of the relationship between structure and the folding and function of proteins. Mass spectroscopy, NMR, and X-ray analysis are providing the basis for the developments of computer-based molecular graphic techniques to more accurately predict the folded 3-D structure of proteins from their primary amino acid sequence.

7.23.6 These techniques will be central to the understanding of the detailed molecular interactions between proteins and their various ligands, whether these be other proteins, small peptides, nucleic acids, carbohydrates or small molecules.

7.23.7 Through the power of gene systhesis it is also becoming possible to mimic the present approach of the medicinal chemist in exploring the structure-activity relationships of polypeptides in relation to the specific biological effect.

7.23.8 A third level at which research progress is being made at great pace is in computer techniques for the comparison, prediction, and hence design of protein structures and drugs. This has been greatly stimulated and driven by the very large number of protein structures being generated by DNA sequencing, and the possibilities in principle through site-directed mutagenesis and other techniques of molecular biology for making new protein structures conveniently and in a large quantity for research or industrial application. The extension of these techniques in computer graphics, to explore the geometry of intermolecular interactions, will become a powerful aid in the design of new drugs and new proteins.

7.24. Monoclonal Antibodies

7.24.1 It is only 9 years since the technology for producing monoclonal antibodies was developed but it has had an impact on almost every field of biology.

7.24.2 The key steps were the identification of methods for fusing cancer cells with cells from the immune system to produce hybrids. These cells do not lose their ability to secrete antibodies in culture as normally occurs. The micro-scale separation techniques required to select single cells possessing the desired function, in this case the secretion of a specific antibody, were also important. It seems probable that this technique will be used in future to create novel cell lines that can maintain desirable characteristics other than antibody production.

7.24.3 Monoclonal antibodies offer enormous potential and the techniques are already being applied in molecular probes for cell and tissue oncogenes through clinical diagnostics. There is scope for their use as potential carriers of toxins for cancer treatment and affinity adsorbents and to provide novel means of drug delivery. Their widespread use in such separation technology will critically depend on imaginative ways to reduce their production costs.

7.25. Cell Biology

7.25.1 In parallel with these studies at the level of the gene, enormous progress is being made in understanding the nature of the machinery used by cells to manufacture, export and move around within and between themselves - the components for their own replication, building new body structures, repairing injuries, mobilising defences, and responding to sensory stimuli.

7.25.2 Elucidation of transport and processing pathways from the endoplasmic reticulum, to the Golgi and hence to the cell surface with recycling back into the cell in some instances is revealing the spatial dynamics and targetting signals for routing materials within the cell. This understanding will no doubt be used to control traffic and direct exogenous substances to specified destinations, in health management and other biological industries in the future.

7.25.3 New understanding of second messenger mechanisms, especially the recent identification of the roles of diacylglycerol and inositol triphosphate and the fascinating indications of the importance of protein phosphorylation on tyrosine residues - is revealing the means by which signals at the cell surface (eg by hormones or other agents) are converted into the instructions for cellular response.

7.25.4 The existence of protein processing mechanisms both at the level of messenger RNA and precursor proteins, is leading to recognition that many variants, alternativesd and combination protein structures are produced in nature. The full reasons for and implications of this are not understood but they do imply a new level of subtlety in the control of protein specificity, whether for structural, enzymic or hormone function. This in turn is likely to suggest new means for intervention in biological processes.

7.25.5 The identification of new agents for intercellular communication, eg the interleukins in the immune system, peptide hormones and prohormones in the brain and endocrine systems will lead to new ideas for the synthesis of drugs.

7.26 Cell Growth and Development

7.26.1 Growth, differentiation and organisation of cells is an outstanding problem in biology of which there is little understanding in either plants and animals. Promising work is being undertaken on the control of gene expression and gene switching. The discovery and characterisation of growth factors which react with specific cell membrane receptors provides an opportunity since it now seems likely that specific growth factors exist for all tissue types. These bind to specific cell membrane receptors and trigger an internal, cellular response. There has been a resurgence of interest in the role of calcium in these cellular processes. Therapeutic products should emerge from an understanding of the action of protein growth factors.

7.26.2 Molecular biological techniques are being applied to the study of cancer. Research indicates that specific genes exist which cause unrestrained cell growth if activated at the wrong time or if their products are synthesised in greater quantity than normal oncogenes. However, malignancy depends on a sequence of events and not a single genetic factor and eventually these will be identified as sequential biochemical events. Models exist to differentiate between the two principal phases of cancer, uncontrolled growth and the spread of disease (metastasis).

7.26.3 The first benefits will be in diagnostics (circulating growth factors/chromosome analysis) but a longer term target will be to transform cancer therapy for the specific control of tumours. A multidisciplinary approach will be required to find the gene(s), analyse the controlling interactions between DNA/proteins, determine how small molecules interact with genes and design molecules to do a specific job.

7.27 Cell Movement and Cell Interactions

7.27.1 A promising area is that which seeks to define in molecular terms the events underlying cell movement and cell interactions, which should provide a basis for cellular organisation in growth and development and may lead to a better understanding of important medical problems such as tumour growth and metastasis.

7.28 Structure and Function of Organised Tissue

7.28.1 Immunology

7.28.2 Research in immunology will create new scientific opportunities with enormous potential for improvement of human health, for producing new techniques of diagnosis, therapy and disease prevention. The latter will undoubtedly prove to be particularly important for the worldwide control of parasitic disease. The tools which will allow development of these opportunities are gene cloning, monoclonal antibodies, immuno competent cell cloning, automated sequence analysis, and peptide/nucleic acid synthesis.

7.28.3 Elucidation of the mechanisms of the immune systems is fundamental to the exploitation of opportunities in immunology. In recent years, using in vitro techniques a substantial understanding has been obtained of the chemical structures of antibody molecules and the processes by which different antibodies are generated through gene rearrangements. Attention has also focussed on the role of the T helper and suppressor lymphocytes and B lymphocytes in responding to challenges by foreign substances (antigens) entering the body. The T lymphocytes regulate the immune response to self and non-self antigens. It is now clear that a variety of human disorders arise from a breakdown in which self reactive cells, or their products, result in injury. Conditions like juvenile onset diabetes, various endocrine disorders, rheumatiod arthritis and central nervous system disorders such as multiple sclerosis are believed to have a strong autoimmune component. A greater understanding is needed of the normal control mechanisms of the immune system in order to identify the trigger mechanisms of the autoimmune response in persons at risk and to develop appropriate means of control.

7.28.4 In vivo immunological responses involve interactions between a wide variety of cells (inflammatory cells) and their receptors. A precise chemical characterisation of both cells products and their receptors will offer considerable opportunities for specific modulation and control of disease. Defining the roles the various lymphoid cell derived hormones (the interleukins) which control the growth and differentiation of immune cells is particularly important. Many techniques including gene cloning will provide investigative routes.

7.28.5 Two kinds of diseases results from changes in the immune system: autoimmune diseases and those in which there are deficiencies in the immune response. In order to investigate possible treatment of deficiencies the study of adjuvants (complex plant, fungal, bacterial extracts which boost immune responses when they are administered with antigens) may prove promising. They may also increase the efficacy of many vaccination procedures, especially synthetic vaccines.

7.29 Neurobiology

7.29.1 We regard the understanding of the physiology and functioning of the nervous system as a challenge of paramount importance in the biological sciences. Despite the resources already devoted to neurobiological research it is such a complex area that a great deal of research remains to be done. The potential benefits are incalculable in social and economic terms.

7.29.2 Control of diseases of the central nervous system and therapy of major mental disorders is an area with considerable potential for exploitation. Pre-senile dementia is common and a substantial proportion of all hospital patients have central nervous system diseases. With increasing age, short term memory becomes impaired whilst long term memory is retained. However, recent advances in neuroscience have opened up the possibility of treatment of disorders such as Parkinson's disease and prevention of one (genetically determined) form of dementia. Biochemical abnormalities and deficiencies in neuro-transmitters are sufficiently understood now to offer the long term prospect that drugs might be developed to enhance and stimulate memory and to aid learning. However, the molecular basis of major psychiatric disorders such as schizophrenia, maniac depressive illness remains unknown.

7.29.3 It is widely accepted that the way forward lies in research which leads to a better understanding of the mechanism of action and characterisation of the neuro-transmitters and their receptors, of the cellular organisation of the nervous system, and the controlling systems governing information transfer and organisation in this system. Such knowledge should lead to new therapeutic strategies, and as an example, the characterisation of brain peptides with opiate-like activities offers prospects for better analgesics, as well as understanding of the molecular mechanisms underlying addiction.

7.30 Whole Animal Response

7.30.1 The area of interest covers a broad range of related subjects directed towards obtaining a greater understanding of intelligence in animals particularly the phenomena of communication, knowledge acquisition, perception, adaptive behaviour. An accepted description of the field is cognitive science; it has a basis in biology, psychology, and linguistics. Opportunities for exploitation of cognitive science are foreseen in fields of human performance, diagnosis and relief of cognitive disabilities, instructional operation designs. One aspect is concerned with the elucidation of brain function and the underlying processes and structures, in order to determine the precise way in which information is coded and used by the brain. Another aspect of the area is related to a field of computer science termed artificial intelligence, which is concerned with development of computer structures to work intelligently in problem solving and learning functions.

7.30.2 Preventive medicine offers much scope for reducing morbidity and mortality in middle and old age, but more understanding is required of the factors which determine the basis of acceptability of behavioural modification.

7.30.3. Technology, Materials and Medicine

7.30.4 Various areas can be identified. The application and development of computational systems is radically changing laboratory instrumentaton, and in the diagnostic field has revolutionised diagnostic imaging, providing the basis for advances such as computerised tomography, nuclear magnetic resonance, and positron emission tomography. It seems certain that developments which will allow non-invasive diagnosis and monitoring of bodily functions will continue, and prove to be of major economic significance; one such device is SQUID (superconducting quantum interference device). Another approach of considerable diagnostic potential is the development of computer based expert systems which should serve as an important aid to physicians. The capacity to provide reagents for specific cell types has led to the development of techniques such as fluorescence-activated cell sorting which is already being used in diagnostic laboratories.

7.30.5 The development of biocompatible materials for use in prosthetic devices has been a major medical advance, and led to developments of a diverse nature, such as arterial prostheses, heart valves, membranes for artificial dialysis, and hip prostheses. However, important problems of biocompatibility remains especially related to the activation of labile blood enzyme systems such as coagulation and complement. An ageing society does provide an important stimulus for technological development to help the elderly and infirm, to enable, for example, mobility and warmth. Much may be achieved by effort aimed at `low cost´, `low technology´, innovation.

7.31 PLANT AND ANIMAL SCIENCES.

7.31.1 We have commented earlier on the buoyancy and optimism about research in the biological sciences. The fundamental role which recent advances in molecular genetics has played in stimulating new research fields in the medical science was discussed. We now consider the research areas in plant and animal sciences which are of long term economic significance. As with medical research, it is the new genetic work which has had greatest impact in plant sciences but the effects have also been felt in the animal science with particular prospects in disease control and development of growth promoting substances.

7.31.2 <u>Plant Science</u>

7.31.3 <u>Control of Plant Disease</u>

7.31.4 The developments in genetic manipulation present new possibilities for control in plant pathology. Recombinant DNA techniques suggest a means of transferring resistance traits from one plant to another. Other approaches include increasing the genetic background of plant seeds to suppress pathogen populations, and the cloning of resistant lines through the regeneration of whole plants from protoplasts. Biological control of plant pathogens by means of antibiotic producing organisms is also a possibility. A much greater understanding is required however of the biochemical events which take place in the cellular disturbances resulting from plant disease. New approaches to disease control might stem from knowledge at the biochemical level of resistance and susceptibility to disease. It has already been established that toxins may be used as screening agents and models for herbicides and that elicitors may be used to protect plants. An alternative to increasing natural resistance to pathogens is to develop greater crop resistance to cost-effective herbicides; attempts to achieve this have been promising.

7.32 Crop Production

7.32.1 Conventional techniques of cereal breeding are lengthy and time-consuming; it is certain that the whole process could be considerably speeded up by the use of genetic manipulation techniques. It is likely also that such techniques could be used to continue to achieve increases in yield when conventional breeding techniques are no longer capable of doing so. With the large cereal surpluses now being experienced in the UK and other developed countries, doubts have been raised about the value of research to increase cereal yield. In economic terms, there are two alternatives to over-production both of which impinge on science and technology. One alternative is to reduce the amount of land for cereal production and use it for other profitable activites in which case total production would be reduced but research would be required so as to maintain and improve yield. The second alternative is to reduce crop yields but in order for the farmer to maintain a profit margin·production costs would need to be reduced. Such costs include seeds, cultivation, chemicals, irrigation, harvesting, transport and the cost of all these could be reduced by appropriate breeding programmes.

7.32.2. In the short term conventional plant breeding techniques, in association with sophisticated analytical techniques, will be of value in improving the qualities of crops, for example, in increasing the quality of grain protein in wheat, and the quality of sugar beet and oilseed rape. However, more fundamental long term work is needed in plant biochemistry on the mechanisms underlying biosynthetic pathways in plants. Such an understanding would provide an insight into the reasons why a plant might deposit starch and not oil in its cells. Biochemical knowledge of synthetic routes in plants may eventually make possible the tailoring of a plant's metabolic machinery, by appropriate genetic manipulations, to produce a crop to a predetermined composition, for example, fatty acid, polysaccharide or protein content. Work is being carried out on the fat and protein composition of plants but research on the carbohydrate component is inadequate.

7.32.3 Research in micropropagation and tissue culture hold the prospect of producing large numbers of identical individuals with superior characteristics. The technology for obtaining consistent embryogenesis in tissue cultures and handling mechanisms for large numbers of propagated microplants requires refining. Cultivation systems for such plant material also needs developing. One approach is to embed the microplants in a pellet of nutrient with a protective coat. In a broader context, however, it is not foreseen that plant cell tissue culture will have any economic advantages over organic synthesis for many substances.

7.32.4 In the very long term, it is possible that by genetic engineering techniques the phenomenon of atmospheric nitrogen-fixation for which only legumes and a few other plant species have a capability might be transferred to non-leguminous crop species. The impetus for research in this area stems from the fact that some 25% of the fossil fuel energy used in arable farming is accounted for by nitrogen fertilisers. The possibilities of nitrogen-fixation by cereals is being investigated, and advances have been made in obtaining an understanding of the gene structures relating to the nitrogenase enzyme complex responsible for nitrogen fixation in bacteria. The energy costs of nitrogen-fixation by cereals does not look promising but in the very long term as fossil fuel reserves dwindle nitrogen fertilisers may not be an economic proposition.

7.32.5 Molecular genetics will be used in the development of natural plant growth hormones for use in, for example, influencing the flowering/ripening process, improving photosynthesis, loosening fruit and affecting leaf abscission. At the present time, such compounds are produced by chemical synthesis or fermentation, but the latter method is expensive and regulatory action may be inhibitory to the former. It is anticipated that the relationship between plant hormone activity and their molecular structure will be elucidated in the coming years.

The practical implication of such developments will be the ability to adapt plant crop to particular environments and conditions.

7.32.6 An avenue for the exploitation of research in genetic engineering in plants is becoming available through research in the regeneration of whole plants from single and selected cells or from protoplasts. All the forage legumes (including alfalfa and clover) can be reproducibly regenerated into plants from proto-plasts, as can many brassicas. But the major cereal varieties have so far proved unresponsive, although other cereals have shown a positive response. At the present time, the approach is largely empirical and further basic research aimed at a better understanding of the biochemistry of plant regeneration is required. Allied to such needs is the requirement for greater knowledge of the cell surfaces of plants. In this context, isolation of the genes controlling continuity of cyto-skeleton will be important. Further research efforts are needed into the dividing and developing cell.

7.32.7 So far as plant breeding is concerned, it is likely that the most useful form of genetic manipulation available to the breeder over the next decade will arise from genetic variation from regenerated plants, with less of a contribution from molecular genetics. Strategic research can now be undertaken using plant regeneration, protoplast fusion coupled with chromosone destabilising procedures and plant regeneration. Protoplastic fusion will be particularly important in obtaining new and useful genetic variation. Such tehcniques have been used successfully for crossing vegetatively propagated species, and it is now possible to make somatic hybrids between sexually incompatible species. The capability has also been developed of using protoplast fusion to transfer cytoplasmically based male sterilty and herbicide resistance. A problem with DNA transformation techniques in plant breeding it that phenotypic traits usually means transfer of several or many genes which may well not be linked to a particular chromosone and therefore not readily amenable to such techniques. However, other methods of genetic manipulation and in particular irradiation of protoplasts which are then fused with unirradiated recipient protoplasts are now enabling such limited gene transfers to be achieved.

7.32.8 Improvement of photosynthesis and control of respiration in plants is often cited as a goal with perhaps the major potential in plant science. However, there is little fundamental knowledge of the key rate-limiting steps in energy-fixation by plants and understanding of the basic complex phenomena of photosynthesis will be long term. The central role of the enzyme ribulose bisphosphate carboxylase (Rubisco) in photosynthesis have been uncovered but even if by genetic techniques the levels of this enzyme in plants were increased, energy fixation might still be limited by other enzyme systems. Similarly, more research is needed on respiration and photorespiration in plants before consideration can be given to breeding techniques to obtain improvements of economic significance in the performance of plants.

7.32.9 In the long term, research into thermal adaptation in plants could be of potential economic importance. Although at a molecular level, advances have been made in research into the effects of temperature on membrane structure, there is still little understanding of the basis of differences in temperature adaptation in plants. More work is needed at a basic plant biochemical level before consideration of prospective breeding approaches is possible.

7.33. ANIMAL SCIENCE

7.33.1. As in plant science, the new techniques of genetic manipulations are likely to have a major impact on most areas of husbandry, for example, breeding, growth, disease control, composition.The effects of inserting new genetic material into animals has already been demonstrated using the gene which synthesises the rodent growth hormone, to produce a "super mouse". This technology has important potential implications. It can enhance food production by stimulating the production of growth hormones in farm livestock. Equally gene "farming" using animals and hosts for the production of high added value proteins could develop from gene insertion technology. Techniques of cell fusion may be used to obtain expression of genes from both parents in animal breeding. Monoclonal antibody techniques will not only be important as a tool in research but also offers new approaches to diagnosis, prophylaxis and treatment of disease. Through recombinant DNA methods a whole new range of therapeutic proteins, hormone substances, antiviral agents, vaccines and feed additives may be possible.

7.33.2. New reproductive techniques such as in vitro fertilisation and ovum/embryo transplantation would speed up and increase selection pressure in animal breeding. Low temperature storage of ova is another possibility. Embryo splitting techniques could be utilised to multiply animals with superior characteristics. Sex determination of reproductive cells before fertilisation could allow production of the economically desirable ratio of sexes in productive animals.

7.33.3. In whole animal systems, endocrine manipulation and endocrine/nutritional interactions is an area with considerable potential. Developments in growth and production physiology has implications for low input/output techniques. Slow release systems for the administration of metabolically active substances could have a major impact on animal husbandry techniques. Constraints on agricultural productivity in the coming years should encourage the search for low input methods. One example might be the flattening of the lactation curve in cows by breeding/endocrine control. In the context of dairy product surpluses, the composition of milk might be considerably modified by research in new production techniques. Animal cell culture techniques offer the possibility of in vitro production of high value metabollically active substances such as hormones.

7.34. BIOTECHNOLOGICAL PROCESSES

7.34.1 Biotechnology is a word which has been coined to cover a wide and diffuse field of scientific and technological endeavour; some individual fields of interest and potential in relation to particular scientific areas have been discussed in preceding sectors. We consider in this section some further promising biotechnological fields more concerned with the exploitation of science and the development of technology than with the underlying science per se . Biotechnology has been defined previously (Biotechnology - Report of a Joint Working Party of ACARD/ABRC/Royal Society) as the application of biological organisms, systems and processes to manufacturing and service industries. Refinements to this definition have placed more emphasis on the application of scientific and engineering principles to both the processing of materials by biological agents and the processing of biological materials to provide products or services. Activities such as medical technology, plant breeding, agriculture are generally not defined now as biotechnology.

7.34.2 Biochemical Engineering

7.34.3 Of fundamental importance to developments in biotechnology is research in biochemical engineering. This field might be described as the application of scientific and engineering principles to the design, development and operation of biological processes. It impinges on a large sector of UK industry, especially food and drink processing, the manufacture of pharmaceuticals and waste treatment. It may also have a significant impact on the chemical industry. However, in most cases process engineers in industry have to rely on a rather empirical approach based on established biochemical engineering knowledge. With increasing international competition in biotechnology, it is essential that the UK has a strong biochemical engineering base and that action is taken to ensure that basic biochemical engineering research is fostered in key areas to provide a sound foundation for further industrial development.

7.34.4 Research ares with potential are:

a. Reactor design - especially the influence of the physical environment and engineering parameters on the behaviour of biological systems;

b. Product recovery - particularly for isolation and purification of proteins, including those produced by recombinant DNA microbiological strains;

c. Instrumentation and process control - including development of sensors and other techniques for on-line measurement and control;

d. General process engineering research in the mundane but essential areas of food and waste treatment;

e. Problems of scaling up to full production plant operation.

It is vital also to ensure the rapid transfer of the product from the laboratory into commercial production, and to allow continuing optimisation of the process to maintain profitability.

7.34.5 Microbial Physiology

7.34.6 Just as the successes of molecular biology in recent years have tended to overshadow the continued importance of studying the biochemistry and physiology of plants and animals so they have with microorganisms. Microbiological research has tended to be concerned largely with conventional microbes such as E coli but there is also potential in studying the nature of organisms capable of existing under extreme conditions such as strongly acid and alkali environments, at ocean depths and at high temperature. Such organisms have already been exploited, for example, alkaphilic bacteria have been used to produce the food additive cyclodextrin and methanogenic bacteria to produce single cell protein. There is a growing interest in the use of microbial and enzyme systems for the specific and efficient generation of chemicals that are hard to synthesise via conventional methods. Selective oxidations and the generation of specific chirality are particularly attractive.

7.34.7 The ratio of publication of patents on biologically active natural products continues to be high particularly from Japan eg the new beta-lactams and avermectins. Many of these are discovered in a research institute or university environment. Very little work is being carried out in the UK university sector on the biochemistry and physiology of secondary metabolite production of the major organisms of interest, the Streptomycetes .

7.34.8 A wider range of organisms is now being used for studies in recombinent DNA with initial cloning experiments being carried out in a more genetically accessible host like E.coli or Saccharomyces cerevisiae followed by suitable transfer to the organism of interest.

Recent developments in microbial physiology promise to facilitate exploitation of these techniques. Temperature-tolerant bacteria are of interest from the high melting point fatty acids which they produce in their membranes as a protection against elevated temperatures. Some salt-tolerant or halophilic bacteria produce bacterial rhodopsin, a molecule which is capable of converting sunlight into electrical energy.

7.34.9 Enzymes

7.34.10 Microbial biochemistry will play a vital role in providing a fundamental understanding of enzyme structure and function.

These will be important for two reasons

i. For the design of inhibitors to facilitate the modulation of biological processes. Microbes will still be the most ready and prolific source of most enzymes

ii. To develop their use as catalysts as more new activities are discovered.

Significant inroads are being made into developing enzymes that function is essentially non-aqueous environments, and on co-factor regenerating systems for transformations that require biological energy. In the longer term protein engineering is expected to contribute to the more widespread use of enzymes by extending their substrate specificity, their stability to variations in ph, temperature and low strength, and their resistance to proteolytic degradation.

7.35 MATHEMATICS WHICH UNDERPINS DEVELOPING AREAS IN APPLIED SCIENCE

7.35 This report highlights those areas of core science which are likely to lead to developments in applied science and engineering. By a similar token, progress will be required in key areas of mathematics so as to underpin the relevant science. A selection of the important areas are summarized below. It should be recognised that a great deal of cross-fertilisation has occurred within mathematics in recent years and that certain topics, such as non-linear equations, now lie at the heart of both pure and applied mathematics. It has been traditional for mathematicians to operate as individuals but the trend towards inter-disciplinary research suggests that more will be achieved in future via group activity.

7.35.2 <u>Logic Theory</u>

7.35.3 This area used to be the purest of all subjects but, with the advent of high speed computing, this situation has altered dramatically. Indeed, the boundary between `mathematical logic´ and the `theory of computation´ is very indistinct.

7.35.4 <u>Coding and Optimisation Theories</u>

7.35.5 Such theories are important for the construction of efficient algorithum in data processing and to overcome problems of computational complexity in the communications industry.

7.35.6 <u>Computer Aided Geometric Design</u>

7.35.7 The application of computer aided geometric design is becoming an indispensable tool in engineering. Molecular modelling using computer graphic systems is also valuable in many scientific areas eg to manipulate and display protein structures demurred from X-ray crystallography. New mathematical techniques will be required in <u>approximation theory involving spline functions and data fitting to function of one or several variables.</u> It should also be noted that the arrival of powerful interactive computing and graphical displays has nurtured a new breed of statistician.

7.35.8 <u>Group Theory</u>

7.35.9 There has traditionally been strong cooperation between mathematicians and physicists in the area of solid state mechanics. Active research is being pursued at present in the science of composites and rheological materials which combine solid and liquid properties.

Group theory is providing solutions to long standing problems of sphere packing and space utilization of relevance to solid state physics and ceramic technology. Developments in pure mathematics particularly cryptology, are leading to very powerful algorithms for factoring prime numbers and will have a strong interaction with group theory.

7.35.10 A feature of the many scientific areas of chemistry, materials, molecular biology, processing etc is the need to understand the links between the known properties of individual components and the aggregate properties that result from bringing these components together. Mathematical modelling on a scale enhanced by increased computer power will make major contributions to progress in all these areas. Parallel development of mathematic theories that lie behind whole classes of observed phenomena will be important to such contributions. For example, <u>catastrophe theory</u> describes the nature of sudden change eg structural failure. <u>Factual theory</u> describes the similarities between geometrical shapes that occur on very different scales, eg can describe catalyst surfaces, and has other potential applications in quantum physics, magnetism, meteorology and biology.

7.35.11 Dynamical System Theory

7.35.12 The general theory of dynamical systems is applicable to many branches of science eg physical studies of lasers and plasmas. In the context of this report it has most importance in understanding the mechanics of fluids; this category includes theoretical aerodynamics, wave motion, geophysical fluid mechanics and the flow of non-Newtorian fluids such as blood and paint. There is now evidence that progress is being made towards an understanding of <u>chaotic behaviour</u> (including turbulence) and three dimensional boundary layer situations of fundamental importance to engineering fluid mechanics. The ability to handle higher order non-linear systems has resulted in some merging between deterministically derived chaos and statistically random turbulence. Some problems are becoming tractable due to the vast increase in <u>numerical analysis in mathematical existence and uniqueness theorems.</u>

7.35.13 Mathematical Biology

7.35.14 This is now emerging as a coherent discipline and is likely to constitute a major growth area. Progress has already been achieved in the use of both probalistic and deterministic models of biological systems eg in ecology, medicine and epidemiology. Other examples include modelling of disease cycles, population genetics, the dynamics of neural networks and the application of catastrophe theory to embryology and problems in biofluid mechanics.

7.35.15 Artificial Intelligence

7.35.16 Human intelligence is believed to be as much dependent on pattern recognition (a parallel processing activity) as a logical activity (a sequential process). Major developments are taking place in the sciences of artificial intelligence, a major thrust at present being in expert systems, computer programmes encapsulating human expertise in a form that can be interrogated. Such systems will have a role to play in capturing and transferring scientific knowledge (place to place or person-to-person) and in enhancing scientific creativity. Substantial progress in artificial intelligence may have to await the successful introduction of fifth generation computers. Ultimately, computers could become self-programming and be able to learn by mimicking nature's ability to build in experiential learning, including the acquisition of natural language.

7.35.17 In summary, therewill be a continuing demand for mathematicians to develop theories which will ultimately enhance scientific creativity and improve technology. In many areas such as artificial intelligence and whole organism response, progress will only be achieved by close collaborative ventures between mathematicians and physical, computer and biological scientists.

CHAPTER 8 - SOME NON-DISCIPLINARY APPROACHES TO SCIENCE

8.1. Success in realising the potential of scientific areas which hold promise will come through uniting many different branches of expertise relating to wholly separate scientific disciplines, particularly those located in physically separated University departments. This is already apparent so far as the contribution of computer science is concerned; there are few fields in which a combination of the discipline expertise to systems analysis expertise, data processing, and the like is not an essential requirement. But in virtually all fields, the joining together of different scientific streams is becoming increasingly important for advance; for example, materials science is concerned with electronics and sensors, with the development of pesticides and fertilisers, and with the development of some advanced energy conversion technology. The union of many different scientific methods obtained by different types of instrumentaton is characteristic of the advances that are likely to lead to economically relevant results.

8.1.2. We are concerned particularly that understanding of the management of areas required to achieve success in multidisciplinary fields is not well-developed. Inter-departmental work in Universities is notoriously difficult. Strong project teams with experts from many fields working together are customary, both in industry and research institutes, but can only be formed when both the task and the range of expertise required for its execution have been well-defined. The more fluid and broad linkages that are required in the pre-definition stage do not seem to come easily in the structure of either Universities or the majority of industrial enterprises, though such temporary groupings can and are habitually formed in industry and research institutes, so as to respond to defined problems.

8.1.3 The non-disciplinary approach to science in Universities and other organisations goes to the heart of the scientific process and the training and instincts of scientists. People trained in non-scientific disciplines are frequently required to develop skills and expertise supplementary to those in which they were first trained. The net effect is to broaden perspectives and widen approaches. In scientific fields, those involved have expected to remain voluntarily or involuntarily in their field of specialism often for a whole career. It is argued that solving scientific problems requires such a single-minded approach, and there is ample evidence to suggest that major breakthroughs have been achieved as a result. On the other hand, it is suggested that this encourages a narrowness in outlook, and in organisations a rigidity and inability to change with the times. Also, the most able scientists are often those who have moved between institutions and used adjacent disciplines in the scientific method. We have already discussed how retraining during working life will become increasingly important for many people and with the rapid rate of scientific advance, scientists cannot escape this possibility also.

8.1.4. In Universities, there are numerous topics and themes which can only be pursued advantageously by removing or ignoring the rigid, traditional, departmental barriers. Molecular beam epitaxy is one classic timely example where physicists, engineers, chemists and material scientists can all contribute constructively. The design of new lasers is another instance calling upon theoreticians and competent scientists from all the conventional or accepted departments. Another example is the use of electron beams for both analyses and characterisation of materials, affecting transformations, and lithographic developments; this illustrates well the need to co-ordinate effort on the part of physicists, engineers, chemists and metallurgists. Yet a further theme is that of heterogeneous catalysis in which inorganic, organic, physical, theoretical chemists on the one hand, and physicists, engineers, metallurgists and chemical engineers on the other, could all contribute constructively and synergistically. On a broader front, the design of new instruments and the development of new techniques is likely to benefit from a cross-disciplinary and multi-disciplinary approach.

8.1.5. One way to look across the sciences might be to approach them in a non-traditional fashion and ignore the conventional breakdown into reasonably defined disciplines. Thus areas of science at a subatomic level impinge on many of the traditional scientific disciplines. At the next level or organisation, atomic/molecular, another range of research fields will have broad scientific relevance. Other levels of organisation such as particulate, microscopic design and system intelligence will yield a spectrum of opportunities for wide application in unrelated disciplines. No doubt an analysis of scientific activities could be made in this way and the scientific community should always be alert to ways of broadening out narrowly developed fields in this fashion. In order to make our point about the interdisciplinary research, however, we have chosen a few specific examples of developments in science and technology which have advanced rapidly because of the interation of ideas and concepts from a variety of scientific disciplines and areas.

8.2. Atomic Collision Processes/Lasers

8.2.1. An example of sub-atomic science with a broad diversity of applications is that of lasers which have wide relevance to atomic and molecular physics, plasma physics, solid-state physics, photochemistry, photobiology, thermonuclear studies, medicine, and many industrial and commercial processes. These applications will be extended by more efficient and reliable lasers particularly by the extension of their spectral range. The x-ray laser, for example, will have exciting applications. The dye laser will continue to be developed to increase the effective spectral range over which ultrashort pulses can be produced, to further decrease available pulse durations and improve reliability. An increased spectral coverage in the near infra-red by colour centre lasers and their operation at room temperature will greatly enhance their usefulness, particularly in optical information processing and molecular spectroscopy. The further development of UV excimer lasers is expected to lead to applications in materials processing, photolithography and data storage.

8.2.2. New lasers will emerge and be developed as a result of a better appreciation of fundamental atomic and molecular collision processes. In particular, charge exchange reactions between ions and atoms offer a possibility `pumping´ levels which are candidates for X-ray laser action. It is interesting to note that population inversion similar to that which occurs in laboratory lasers is observed in lasers in interstellar media.

8.2.3. The successful development of fusion reactors may prove to be a decisive factor in continuing economic and social development in the next century. Atomic collision processes are very relevant in this area also. However, there is a large gap between what is known and what is required for large projects such as JET. Studies of ion-ion and electron-ion collisions are directly relevant to magnetically-confined and inertially-constrained fusion plasmas. Injections of fast atomic beams into plasmas is a powerful method of ancillary heating and injected atom, ion or laser beams are also used as diagnostic probes. More sophisticated methods are being developed in which energy-resolved electrons probe molecules and reveal short-lived excited states and other details of molecular structure. This has led to commercially produced equipment for use in, for example, chemistry and new techniques have reduced data collection times by two orders of magnitude. Electron optical apparatus will find increasing applications in surface physics, metallurgy, biology, medicine and elsewhere. Another technique which in time will find wide applications across disciplines, involves probing molecular structures with positron beams. Ambiguities associated with the inherent indistinguishability of electrons are thereby removed. Other developments include studies of the angular distribution of radiation produced by collisions between spin-polarised electrons and polarised atoms, and a wide variety of measurements of the interaction of synchroton and laser radiation with atoms, molecules and ions.

8.2.4. General progress in the above-mentioned areas will require a general awareness amongst the physics community of complementary developments and research discoveries in plasma, atomic and astrophysics. The benefits will have a dramatic impact in science and technology.

8.3. MOLECULAR ELECTRONICS

8.3.1. It is a well known feature of intellectual history that most seminal new developments take place between the traditional borderlines of mature disciplines. In many cases the interface is relatively well defined and involves only two traditional subject areas. Molecular electronics is distinctive in that it requires inputs from several disciplines and encompasses a broad scientific base involving physics, chemistry, biology and materials science together with electronic engineering. Current areas of interest which offer considerable promise if there is efficient co-ordination between scientists and technologists and appripriate investment of research effort, are: polymeric photoconductors, semi-conductors and superconducters; photochromic and electrochromic materials for displays and high density ionisation storage; pyroelectric and piezoelectric organic materials for use in detectors and transducers; liquid crystal systems for displays and in switching and memory elements; chemical and biological sensors; non-linear optical materials useful in integrated optics and optoelectronics; polymers for use in microlithography.

8.3.2. Molecular engineering, the ability to manipulate the molecular architecture of a materials to optimise a specific physical parameter or figure of merit, is a common theme in many aspects of molecular electronics. Although in the first instance the objective is to acieve improved device performance, the fundamental science is normally more deeply explored as a consequence. The role of the innovative chemist in designing and synthesising these novel molecules is clearly essential. The resulting materials may themselves be relatively inexpensive, but the investment required to develop useful devices is usually considerable and also depends on the ingenuity of the physicist and the engineer. Moreover, it must be remembers that the discipline interface with bioscientists is also critical. For example, the work of certain biologists on vision and the brain, and on information processing is likely to have considerable relevance. Indeed, in those cases with longer time horizons such as the use of macromolecular self assembly to produce concurrent processor networks, the emphasis is totally on fundamental work, much of it requiring a detailed knowledge of biology.

8.4. ROBOTICS

8.4.1. The traditional compartmentalisation between design and its methodology, production technology and the man-machine interface is gradually being broken down due to the application of information technology in the manufacturing industry. Such integration will become possible by carefully co-ordinating all aspects of the manufacturing system by extensive use of compterised data bases. The manufacturing processes such as spot welding, materials handling, finishing and coating, are welding and assembly will be automated using robots.

8.4.2. Current robots are capable of high speed precision and repeatable position control. However, the availability of force sensing, the ability to control the force exerted by the robots grasping mechanism is very limited. Future advances will require lighter, more responsive movements where continuous force control is available. Such artificial limbs will incorporate muscle analogues based on knowledge of equivalent biological systems. Collaborative research between biophysicists and materials scientists could, for example, lead to polymeric materials having contractile properties responding to electronic stimuli. Current robot vision capabilities are two dimensional, binary and severely restrict space-shape differentiation. Novel three dimensional systems will depend on developments in sensor technology. Interdisciplinary research will be required to produce selective, highly sensitive, cheap and robust sensor elements capable of working in hostile environments for long periods without servicing. Another drawback of present robots is that programming systems are incompatible with most standard operating systems and programming languages. Smart systems are required for real time distributed operation. The emergence of parallel processing networks allied to artificial intelligence will, of course, have a profound effect on the field.

8.4.3. The interdisciplinary nature of information technology in the manufacturing industry will require close co-operation between mechanical, electronic and control engineers; their progress will depend largely on progress made by computer and materials scientists.

8.5. MATHEMATICAL BIOLOGY

8.5.1. Mathematical biology is now emerging as a coherent discipline which involves close co-operation between bioscientists and mathematicians. Major groups are to be found in biology, mathematics and medical departments.

8.5.2. Applied mathematicians face challenging problems in modelling biomechanical phenomena. For example, biofluid dynamics is concerned with animal locomotion, and heat and mass transport by fluid flow systems within an animal. Important problems include blood flow in vessels under compression and diffusion modelling in drug therapeutics. There is a distinct subject know as biometrics governing stastical methods in biology and medicine; the field of deterministic mathematical modelling embraces ecology, medicine and epidemiology. Much of this research involves reaction - diffusion theory and resulting phenomena which can be related to regeneration mechanisms. There are many other areas of interest including modelling the propagation of electrical impulses in axons, the dynamics of neural networks and the application of catastrophe theory to embryology.

8.5.3. In summary, the modelling of complex biological problems is providing a challenge which relies heavily on close collaboration between bioscientists and mathematicians, both at the experimental and modelling stages.

8.6. PROTEIN CHEMISTRY

8.6.1. The size, complexity and instability of proteins have previously constituted a barrier to the full utilisation of their enzymic and pharmacological properties, but this has been transformed by the development of a number of complementary techniques for the isolation, analysis and synthesis of proteins.

8.6.2. The ability to transfer genetic information into cells to code for the production of specific proteins, offers the prospects of large scale preparation of commercial valuable molecules, such as insulin, using relatively simple microbial systems as the host organism. The widespread transfer of these techniques to animal and plant cells will be achieved in the next five years. Mammalian cells have sever[illegible] advantages over bacterial cells as hosts for foreign protein expression, particularly for proteins that micro-organisms do not make well or for proteins that require modification after synthesis to enhance their activity. It is also easier to determine the function of specific transferred genes from the properties conferred on the host cell when it is from an animal or plant rather than from a bacterium.

8.6.3. Expression of genes in a foreign host also allows biochemists to acquire experimental qualities of proteins of important in biology and which normally occur in only minute quantities. For example, adequate amounts of cell-receptors are beginning to be made available and this will greatly facilitate the study of receptor function and ligand binding.

8.6.4. Identification of the proteins responsible for important cell functions has been enhanced both by the use of techniques to identify subtle genetic differences between cells (subtraction hybridisation), and by using the unique selection property of antibodies to purify a particular protein. Once isolated, new proteins can be analysed by using micro-methods to establish their amino acid sequence. This technology has largely replaced the need to collect and concentrate large amounts of biological fluids as a means of isolating important proteins.

8.6.5. Perhaps the most powerful development influencing protein chemistry has been the invention of new methods for chemically synthesising genes using step-wise polymerisation of the component nucleotide bases in the correct sequence code for a specific protein. This technology, combined with the ability to produce foreign proteins by gene insertion in micro-organisms, opens the way to `protein engineering´. This subject is in its infancy but offers the opportunity to make proteins to order, which will enable the greater understanding of the relationship between structure and folding and function of proteins. A vast number of permutations of protein composition are possible. Mass spectroscopy, NMR and X-ray analysis of proteins will provide a basis for the development of computer programmes to predict the folded 3-dimensional structure of proteins from the amino-acid sequence.

8.7 Immunology

8.7.1 There has been an explosion in knowledge of the mechanisms and cellular relationships in immunology. The subject is moving rapidly from the descriptive to the mechanistic level, from which a unifying theory could emerge to describe the way the immune system recognises and combats foreign material, including infectious agents and proliferating malignant cells. Molecular biology has had a significant influence and this will accelerate during the next four years to define more fully the controlling substances.

8.7.2. New insights will be gained into the role of the immune system in degenerative diseases, such as arthritis and skin disorders. Therapeutic exploitation of this knowledge will probably be via the administration of analogues of the natural protein control factors, rather than small organic molecules, because of the need for specificity. This will require protein engineering for success.

8.7.3. An intense period of research activity in immunology is foreseen in the next five years. However, only isolated parts of the very complex lymphocite membrane have been characterised and further development will depend on learning more about cell-cell interactions. Lymphocytes produce large amounts of sugar-protein conjugates, and these may be responsible for inducing different types of effect.

8.7.4. Brain-immune system interactions are becoming more important. Greater knowledge of immune balance will be necessary before monitoring becomes useful in diagnosis.

8.8 Plant Molecular Biology

8.8.1. Genetic manipulation of plants, using recombinant DNA technology, has become feasible because of progress in the isolation of single plant cells and their subsequent culture to regenerate whole plants. It is anticipated that further improvements in plant cell culture techniques will be made, possibly based on understanding derived from mammalian cancer and cell differentiation work. The first carrier for transferring genes into plants has been developed and others will follow quickly. This opens the way to rapid progress in plant molecular genetics. The problem will not be how to transfer genes, but which genes to transfer.

8.8.2. Such genetic manipulation techniques offer the opportunity to produce specific, positive effects in plants that cannot at present be achieved with chemicals. Understanding of plant processes at the biochemical level will result from the use of monoclonal antibodies and DNA probes, together with the production of sufficient quantities of plant enzymes and receptors for studying the molecular interactions. Alternatively, the insertion of new or modified genes could change the function or efficiency of a plant enzyme.

8.8.3. Successful manipulation of plants via genetic engineering is likely to be significantly more difficult than in bacteria and yeast because of the greater quantity of genetic information in plants and the more complex genetic organisation of the plant cell. Additional problems are the lack of fundamental understanding of plant cell biochemical processes and the need to move combinations of genes to achieve the effects required. The identification of genes and lack of understanding of plant metabolism are currently the inhibiting factors.

8.9 Catalysis

8.9.1. Although in the past, developments in heterogenous catalysts have been the result of trial and error experimentation, it may be possible in the future, through developments in scientific understanding, to predict which catalysts will be the most suitable for particular reactions. Areas of special interest are multifunctional catalysts, geometrically constrained reactions, and chiral "templating" by almost blanketing an active surface with a chiral substance such that the products formed in the uncoverd areas are forced to have the same chirality. However, the number of UK schools working directly on catalysis is decreasing, and they are being replaced by schools of surface science.

8.9.2. The reacting of an ionic compound in aqueous solution with an organic compound in a non-polar solvent has always presented a difficult challenge. Phase Transfer Catalysis is a new technique which brings the reactants together and allows the ionic reagent to work in an organic medium. This is an exciting and rapidly developing area of research which could be used for chemical synthesis eg polypeptide building of controlled structures. They could also be applied to PEEK synthesis to reduce the need for recrystallisation and distillation. Steric factors can be included. Polymeric phase transfer catalysis might provide a link to ionically conducting polymers and materials with other desirable electrical properties. It might also be possible to construct membrane reactors and separators from functionalised polymers.

8.9.3. Research in the structure and behaviour of enzymes will lead to new developments in chemical synthesis. Enzymes are highly specific in their action and will catalyse otherwise forbidden reactions. They could provide a direct route to nitrogen fixation. A particularly attractive area is synthesis leading to chirality, where high quality traditional chemists are now beginning to get hands-on experience.

8.9.4. Bio-catalysts require an energy input and alternatives to the natural complex electron-donation systems are being developed. New electro-chemical routes to speciality chemicals may become available by immobilising enzymes on electrodes. It might be possible to activate or deactivate enzymes by light stimulus.

8.9.5. Three developments from other research areas which could be important influences for the future of catalysis are (a) the possibility of laying down catalysts on a surface, atom by atom, using techniques such as molecular beam epitaxy, (b) the application of fractal theory (c) the use of ultrasound as a means of producing homogenous catalysts and for cleaning unwanted by-products from heterogenous catalytic structures.

8.10 Process Technology

8.10.1. Innovation will be stimulated by the more widespread use of economic small-scale plants that do not involve large amounts of capital.

8.10.2. The optimal use of energy in the chemical and process industries will depend upon better use of low-grade heat. This will increasingly call for the use of heat pumps, Rankine cycles and heat storage materials. Also the need to use low-grade heat could increase the use of biological transformations.

8.10.3. Modern laboratory physical and organic transformations, new technologies in other fields such as magneto-hydrodynamics, and novel analytical techniques all warrant examination to see if they could be scaled up to provide the basis for alternative chemical and industrial process technologies.

8.10.4. We currently lack good large-scale processes for separation. Powerful instrumental techniques exist eg high resolution chromatography, perhaps using supercritical fluids, which might be scaled up, and chiral separation methods are now becoming available. The large-scale use of biological processes will put an emphasis on separation technologies that are not so energy dependent as at present. Biological separations could use enzymes in porous containers and hollow fibres.

8.10.5. Colloid sciences principal contribution to process technology has so far been in solving separation and isolation problems, such as solid-liquid separation. In the future, however, there is likely to be substantial progress in using colloids and interfaces as the sites for chemicl reactions. Examples of their use might be:-

a. highly exothermic reactions carried out in the internal phase of an emulsion, allowing the continuous phase to act as a heat suite;

b. perfectly orientated vinyl unsaturated molecules at interfaces polymerised to high stereo-specific products.

8.11 Surface Science

8.11.1. The science of the atomic surface layers of solids and the interaction of such surface layers with other solids, liquids and gases has developed rapidly in recent years, and will form the basis of important new technological developments in many areas of science over the next decade or two. Advances in surface science have relevance for solid-state physics and chemistry, for example, in the controlled surface generation of crystalline materials for use in semi-conductor technology. Heterogenous catalysts, already mentioned earlier, enhance the rate of chemical reaction at gas-solid interfaces and will continue to have important implications for technologies associated with petroleum refinement, production of polymers, fertilisers and synthetic fuels. Interaction phenomena at liquid/solid interfaces are relevant particularly so far as combatting corosion and embrittlement of materials are concerned. Likewise, solar energy conversion (photo-chemistry), nuclear energy, and other electrochemical reactions as well as the development of the technology of sensors entail phenomena at solid/liquid or solid/liquid/gas interfaces. In analytical chemistry, the use of electrodes as molecular sensors is becoming increasingly important.

8.11.2. It has been suggested to us that "solid-state" was a dominant theme in physics between 1950 and 1970, and that in the next two decades, and possibly beyond, an interdisciplinary "surface science" will play an equally important role in both physics, chemistry and materials technology. UK research in reactions at surfaces of metals is relatively strong, but less advanced, possibly, as applied to the surfaces of non-metals, such as oxides of catalytic importance, or of the technologically important semiconductors such as gallium arsenide or doped silicon. There is abundant scope for developing solids with tailored surfaces for desired properties.

PART III - APPENDICES

APPENDIX I - RESOURCES AND MATERIAL SUPPLIES

1. It is not our intention in this Appendix to contribute to the continuing debate, started in 1970 in publications such as `Limits to Growth´ by the Club of Rome, on projections of resource availability in the world, but to present our comments on the ways in which trends in resource supplies might affect the needs for and development of technology. On the general question of resource availability we would support the views expressed recently by the Henley Forecasting Centre that such availability depended on the meaning attributed to scarcity. Thus it has been argued that availability/security of most commodities is a function of supply/demand which is reflected in the market-place by price fluctuations. In the case of a resource which is clearly finite substitutes will be found, or if not, alternative forms of economic activity which do not require the resource would be carried out. The long term trends in the real price of commodities also reflect their relative availability/scarcity, and such trends for most non-renewable resources have been consistently downwards, on average, over the last century or so.

2. However, technology and particularly competition in innovation is rarely concerned with the absolute amounts of resources but with factors such as relative costs of materials which can perform similar functions, long term pricing of resources, inherent advantages of one material over another, ease of obtaining supplies, change of balance in demand, etc. In the passages following we discuss the availability of resources and material supplies in the context of such factors.

Energy

3. Energy is essential for all economic activity and any consideration of areas of science with economic potential would be incomplete without reference to its supply and use. Many predictions have been made and scenarios of energy supply and demand in the future have covered a very wide range. The majority view now seems to be that an overall shortage of energy in the next 20 years or so is unlikely, although the possibility of occasional shortages, particularly of oil, cannot be discounted.

4. However, it is a characteristic of the energy scene that large cycl[illegible] of alternate shortage and abundance occur, as the market over-reacts in increasing or reducing the large and long-lead-time investments required to bring new supplies to the market place. In cost terms, therefore, fluctuations in the real price of energy are likely, but it is not clear whether the long term trend in energy costs will be upwards or downwards. Rapid growth in energy demand which would put renewed pressure on energy supplies seems unlikely to return to the industrialised market economies but may well occur in the emerging, third world economies. Although oil will remain the most important fuel for some time it seems very likely that gas, coal and nuclear power will all play a relatively bigger role worldwide than in the past.

5. The present United Kingdom position mirrors that of the world as a whole but the UK has the advantage of indigenous supplies of oil, gas and coal. As an example of possible future trends in the UK the following data is derived from the recent Esso UK Energy Outlook. The use of coal, gas and nuclear power is expected to grow and oil decline somewhat, although in value terms oil will still be the most important fuel in the year 2000.

UK Primary Energy Demand
(million tonnes oil equivalent)

	1983	2000
Oil	72	64
Natural Gas	44	55
Coal	66	69
Nuclear etc	12	21
Total	194	209

(Source: Esso UK Energy Outlook 1984/85)

The primary energy used per unit of GDP in Britain has been falling for many decades and is projected to continue decreasing over the next twenty years; because of changes in the structure of the economy, because of a general shift to higher grade fuels and also because of increases in the efficiency of utilisation of energy in basically unchanged operations.

6. As a result of these changes and the recent decline of energy-intensive industries, the amount of energy actually sold to industry has fallen dramatically since its peak in 1973 from 103 Mtce to 68 Mtce. In contrast, the domestic, commercial and transport sectors all now consume more energy and therefore in aggregate a much larger fraction of the total, as the table shows. Use of energy for transport has increased most, from 21% to 26% of the total, and will probably continue to grow as more people own cars and use them more extensively. The table also shows another aspect of UK energy use, the overwhelming importance of clean, convenient fuels (oil products, gas and electricity) over solid fuels as far as final users are concerned. Thus the reduction in the use of petroleum products from 1973 has been almost matched by an increase in the use of gas. Electricity has remained stable and solid fuels have almost halved, despite the intervening oil crises of 1974 and 1979. It is most unlikely that advanced industrialised countries will be prepared to reverse the current trend towards using more sophisticated fuels to any significant extent.

ENERGY SUPPLIED TO FINAL USERS IN THE UK, 1983

By Sector	% total	By fuel	% total
Industry	31	Petroleum Products	41
Domestic	29	Gas	31
Transport	26	Electricity	14
Other users	14	Solid Fuel	13
TOTAL	100	TOTAL	100

Source UK Energy Statistics 1984 (HMSO)

Total use = 54.2 Gtherms

Mineral Resources

7. The UK is heavily reliant on the supply of basic minerals and metals from abroad. But as with energy resources the real price of mineral resources have decreased, on average, in the last century or so, suggesting that such materials are becoming relatively less scarce in the long run. Of greater relevance than the absolute amounts of reserves available, however, is the relative availability, vulnerability, and essentiality of supply. The concentration of supplies of mineral elements in particular localities of the world is of importance to such considerations. Interruption of supplies, for which substitution by other materials might prove difficult could result in the short to medium term from this concentration. An assessment by the Materials Forum in 1981 suggested the following eight metals merited the highest priority in terms of strategic

supply.

Chromium
Cobalt
Tungsten
Manganese
Molybdenum
Niobium
Platinum Group
Vanadium

For all these metals, the UK is 100% dependent upon imports.

8. Such strategic metals find applications in areas such as advanced metallurgical processes, special alloys, catalysts, automated machinery etc. Chromium, manganese, niobium, molybdenum and vanadium are of particular importance in steel manufacture. The major areas, many of which are in high technology fields, of application of these metals are: metals are:

Chromium - metallurgy, alloys, refractories, chemical industry, foundry sands, corrosive environments

Cobalt - magnets, superalloys, cemented carbides, tool steels, catalysts, pigments, metal-organics. The aerospace and power plant industries are particularly dependent on cobalt.

Tungsten - tungsten carbides, alloy steels, electrical and chemical industries. The metal is of particular importance in advanced manufacturing machinery and drilling technology.

Manganese - metallurgy, alloys, batteries, catalysts. Steel manufacture is highly dependent upon manganese

Vanadium - high speed steels, forging technology, special alloys with steel for high strength pipelines, cold pressed steels, special alloys with titanium for aerospace industry, catalysts.

Molybdenum - iron and steel metallurgy, superalloys, catalysts, pigments, lubricants, mill products, welding products. Of importance for production of steels for the offshore industry. Also used in aerospace industry and could be of growing importance in the automotive industry.

Niobium - alloy steels, superalloys, specialised applications in the nuclear, space technology and superconductor fields. Microalloy steel of niobium is replacing mild steels in many applications particularly in the USA and Japan as a result of more stringent specifications.

Platinum group - besides platinum, the group includes palladium, rhodium, iridium, ruthenium and osmium. These metals find uses in high growth industries such as petroleum, chemical, automotive, electrical, glass, dental and medical, jewellery. Platinum and palladium have become essential to the automotive industry in catalytic converters to control exhaust emissions from vehicles. The group finds many applications in manufacture of electrical and electronic devices. In the chemical industry, reforming, cracking, autoexhaust oxidation, and isomerisation are all dependent on the platinum group metals.

We draw attention to these metals in particular because of their vital importance to the growing high technology industries, and in many areas of their applications it would be extremely difficult to obtain suitable substitutes.

9. Other natural elements, which may not be classified as strategic are as important as those discussed above because they are used in products where a high economic value is added in production from primary resources, by products or waste materials. Important products in this category are the highly purified materials required for new advanced technologies in communications and information. Such materials include silicon, germanium and gallium and certain derivatives of these. Niobium is also of interest for potential application in super conducting magnets. More attention is required to be focussed on devising and developing new techniques for their extraction and purification when used in the electrical/electronics industry, the added value in relation to initial raw material cost may be as high as 10^6 for these materials.

10. So far as the major common metals are concerned the chief metallic elements, ordered in terms of usage, are:

Iron
Aluminium
Copper
Zinc
Nickel
Titanium
Magnesium
Cobalt

Perhaps the most significant change in terms of usage over the decades has been the increased production of aluminium, and it is now the second most widely used metal after steel. This increase has been due to its substitution for copper and steel in a variety of applications and its use in new products such as aircraft, packaging material, etc. At the present time, aluminium usage is about 4% of steel consumption in developed countries but by the turn of the century, the ratio is predicted to be 8%. Recent technological developments in non-metallic materials, for example, ceramics, composites, optical fibres, etc have presented a challenge to traditional applications of some of these common metals which may h[illegible] a significant effect on their use in the future, with considerable economic, technological and environmental consequences.

11. In 1982 the House of Lords Select Committee on the European Communities published a report on `Strategic Minerals'. The report highlighted the close dependence of the European Community on external countries for its supply of metal and non-metal minerals. Many of the metals discussed above were considered to be critical in relation to the contribution made to European national economies and the non-metallic materials asbestos, fluorspar, phosphate rock, and sulphur also had a critical role in the Community's economy. Minerals that were considered to be critical economically to Member States, vulnerable to supply disruption, and for which the Community was highly dependent on supplies from outside sources, were chromium, manganese, phosphate rock, and the platinum metal groups.

Synthetic Materials

12. Synthetic materials have been a major growth industry in the last two or three decades, and most aspects of modern living have become dependent on the use of modern synthetic materials. The communications and information, automotive, textile, medical instrument, packaging, cordage industries are all major users of synthetic materials produced by the plastics industry. In 1980, Europe consumed about 13.5 million tonnes of synthetic polymers, excluding textiles and natural rubber of which about 13% or one and three quarter million tonnes is used in the UK.

13. So far as supplies of synthetic materials are concerned, some strategically important non-metallic materials with important defence applications have not proved attractive to major materials maufacturers in the UK and are largely imported from abroad. Such materials include high temperature adhesives, elastomers, engineering thermoplastics, fibres, and resins for composites. Although the markets may not be large these materials are crucially important in a wide variety of products. Another group of plastic materials, thermosetting resins, are used in large quantities by UK industry. This group is composed of six main categories, alkyd resins, aminoplasts, expoxide resin, phenoplasts, thermosetting

polyesters, and polyurethanes. The commodity raw materials for thermosetting resins are often produced from a common manufacturing stream, of which there may only be one supplier in the UK. The recent commissioning of large chemical production facilities in the Middle East capable of producing from flare gas commodity raw materials such as methanol, phenol and urea more economically than can the UK has considerable implications for the supply of such materials to the UK industry.

14. The bulk polymer industry is dependent upon ethylene, propylene, butadiene, and benzene as the chemical building blocks for the production of materials such as polyethylene, polypropylene, polystyrene, polyvinyl chloride, etc. In the next decade or so, such building blocks will be manufactured from products of the oil and gas industry, for feed stocks such as naptha, gas oil, ethane and liquid petroleum gas, however, it is possible that new feedstocks from coal or biomasss might be required towards the end of the century. Over the next few years, products based on ethylene are likely to be affected by increasing low-cost production overseas. The Middle East and Canada, in particular, are developing an indigenous chemical industry based on cheap methane, and the initial effect of this will be a substantial build-up of manufacturing capacity for low density polyethylene and high density polyethylene in those areas, which will be highly competitive with European production. This may suggest the need for development of new polymers by the UK and Europe in order to create new markets.

15. Ceramics include a wide range of non-metallic inorganic materials which have applications in advanced technology. Such materials include, glass, cements, conventional ceramic materials like porcelains and clay-based materials, and composites based on ceramic particles and fibres. Products of ceramics or incorporating ceramic material are finding increasing applications in many economic sectors and are beginning to substitute for metals in some areas. The building and construction sectors have traditionally been the major users of ceramics, but uses in the growing high technology industries particularly for special ceramics are increasing rapidly. These areas include the nuclear industry, advanced

16. The basic compounds from which ceramics are produced are relatively few in number, being generally the oxides of aluminium, silicon and magnesium, with perhaps the addition of other substances formed from silicon, carbon, nitrogen and oxygen. Newer ceramic materials include compounds of boron, tin, molybdenum, and barium, without the presence of oxygen. The processes used in ceramic fabrication depend on the formation of solids from powders by sintering, melting or chemical reaction. New processes are required and will be developed to produce ceramics with enhanced properties and a wider variety of applications. Increasingly ceramics are being made from pure powders produced by the chemical industry or pre-treated natural raw materials rather than from naturally-occurring raw materials. The production of powders for ceramics represents a new opportunity for technology in this developing industry. Plentiful supplies of raw materials are available in the UK for the production of traditional ceramic materials, such as concrete, brick, glass for the construction industries, but some of the more unusual materials used in ceramic manufacture are supplied from abroad, for example zironia-alumina-silicon compounds used in some processing sectors.

17. Coal has already been discussed in the context of energy resources trends, but coal is also an important resource for the production of material and chemical feedstocks; before the discovery of oil and gas it was the major source of such production. It is not anticipated, however, that manufacture of materials and chemicals from coal will be competitive with manufacture from feedstocks produced from indigenous oil and gas sources within the next two decades, unless new catalysts become available quickly, but it is possible that attention will be turned towards coal as a source of feedstocks towards the end of the period. Research and development into new coal processing technologies during the intervening period could be important, since in the long term coal may well form the basis of many products produced by the chemical and other industries.

Renewable Resources

18. The UK is highly dependent upon imported sources of timber and wood products which are a major deficit on the balance of payments. At the present time self-sufficiency is wood production expressed in terms of

wood raw mateial equivalent is in the region of 12%. It has been suggested (ref) that the potential for a high degree if self-sufficiency in the UK is not possible because of competing demands for land use but self-sufficiency could increase to 18% by the turn of the century. An important consideration in the supply of wood is the cost of production in the UK compared with world prices, which are influenced by a variety of often unpredictable factors. Present scenarios project that the world prices of wood products will remain broadly constant in real terms over the next few decades and supply will shift broadly in response to demand. Pricing factors coupled with the potentials for substitution and recycling make it unlikely that an overall shortage of wood will occur in the next 10 to 20 years. Recycling already plays and will continue to play an important role in the UK´s wood economy. Trends in wood suply and demand could be influenced by technological and other developments. Changes in incentives for agricultural production could affect the amount of land available for other purposes such as afforestation. Genetic engineering, to improve wood stocks, in association with improve forestry techniques might further increase timber output. On the other hand, the prime uses of wood are for paper and newsprint, fuel and for construction, and substitutes are available for all such purposes which could have some effect on the demand for wood. However, new uses for wood are being investigated, for example, for production of methanol or bio-engineered materials.

19. Lignocellulose, which comprises lignin, cellulose and hemicellulose, is a major renewable resource produced by carbon-fixation using energy derived from light by plant materials. A recent estimate puts the total weight of material produced by plants in the UK each year at 24.8 million tonnes of dry matter of which agricultural crops account for some 60%. Some 12 million tonnes of waste in the form of straw, crop residues, etc result from such production. This waste might provide a useful source of lignocellulosic feedstocks if suitable fractionation techniques can be developed. Once extracted such feedstocks might form a basis from which to produce commodity chemicals. Processes are available for the production of glucose, hemicellulose sugars, and lignin. Glucose is a substrate for production of many downstream products including ethanol, acetic acid, butane and butanediol. Lignin and hemicellulosic sugars have possible uses as adhesives, paint fillers, concrete and tarmac, xylitol and fermentation

products such as ethanol. A major problem in the further utilisation of lignocellulose wastes is the cost of their collection and transport. However, total value of the products from straw utilisation is well in excess of the total costs of straw collection and transportation. In the long term, lignocellulosic materials may be a valuable renewable resource since they are the most abundant organic materials world-wide, and their improved utilisation would not only provide a valuable resource for industry, but also contribute to the reduction in environmental pollution from liqnocellulose wastes.

20. In 1978, the average daily per capita use of water each day in the UK amounted to some 329 litres, although water use varied between regions from as high as 473 and 443 litres respectively in Northern Ireland and Scotland to 267 and 276 litres respectively in the Midland and South Western areas of England. Roughly two thirds of the water supply ie that which is unmetered, goes to household and commercial use, whilst the remainder is metered for industrial use. Broad changes in water usage during the 1970's are illustrated by the following figures

Water abstractions in England and Wales 1971 - 1978

10^6 cubic metres per annum

	1971	1978
Public and private water supply	5236	5774
CEGB	6897	4534
Other industry	3363	2435
Spray irrigation in agriculture	87	112
Total	15,583	12,852

(Source: Water Data Unit, Department of the Environment)

During the 1970's, total water usage decreased due mainly to major reductions in usage for electricity generation and by industry generally, reflecting a decreased economic activity and increased efficiency of use in those areas. Water usage in the public and private water supply increased during that period due to the population increase, growing ownership of domestic household equipment which requires water, and increase in household use of water for various other purposes, such as gardening, car washing, etc.

21. Rainfall in the United Kingdom averages in the region of 900-1000 millimetres per annum. Scotland has the highest annual rainfall at about 1450 mm and England the lowest of some 840 per annum; area differences within and between regions show even greater variations. So far as is known, the consequences of such variations have not been considered systematically. From an economic viewpoint, although broadly speaking the weather is a major factor of which account is taken in many activities, a a more positive approach might be taken to the exploitation of weather phenomena in technology and innovation. A considerable amount of precipitation which reaches the surface is lost by evaporation~~s~~ which ranges from more than 60% of rainfall in the areas with more favourable climatic conditions to less than 40% in areas with less favourable climates. As a result of regional differences in rainfall and evaporation rates the residual water available for replenishing rivers, lakes, reservoirs, etc may be less than 25% in some areas and more than 75% in others. Such differences have consequences for water supplies, economic activity, agriculture, and the environment.

Non-metallic mineral resources

22. The bulk of non-metallic mineral resource production is made up of low unit value, large tonnage aggregate materials such as sand and gravel, limestone and igneous rock. Such materials form the raw materials for the ceramics, fertiliser, chemical, and glass and steel industries. For many non-metallic mineral resources the UK has large indigenous resources and is a major exporter of some materials, for example, high quality ball clays, sand and gravel. In spite of the UK's natural endowment with extensive resources, some non-metallic mineral materials are required to be imported in volume (ref). Possibly the most important is phosphate rock, but other important imports include crude sulphur, titanium minerals, bauxite, and asbestos although imports of the latter have declined over recent years because of health concerns. Processing of minerals has played an important role in the development of indigenous resources; with value added by such processing, mineral technology could

play an increasingly important part in expanding products and value [illegible]om present resources and might allow exploitation of resources hitherto regarded as unsuitable for use.

23. The UK is a major source of some non-metallic mineral resources, for example, we are the world's third largest producer and largest exporter of kaolin. Extremely large deposits of salt also exist which are exploited for home consumption but exports are relatively small compared with some other countries, for example, West Germany and the Netherlands each export ten times as much salt as does the UK. Talc is also an under-exploited mineral in the UK, production amounting to about 18 thousand tonnes compared with 300 thousand tonnes in France and 1.5 million tonnes in Japan. The country also has significant deposits of gypsum used in the manufacture of plaster, plaster-board and cement, and rock salt and potash. Thus there are several major non-metallic minerals of which great advantage might be taken in terms of exploitation and exportation. Other major non-metallic minerals have to be imported and it would be worthwhile considering whether the UK has indigenous resources of these which could be profitably exploited. Disciplines in mining technology in the universities should investigate new processes for extracting and refining both metallic and non-metallic mineral resources in the UK; technologies for producing refined products from minerals indigenous to other countries particularly in the underdeveloped regions of the world should also be examined because of their export potential.

Other Considerations

24. To round off this section, we mention briefly, a broader issue or problem related to natural resources. This concerns the loss of top-soil from agricultural land. The problem is relatively unimportant in the UK, but in many developing countries, the rate of loss is reaching proportions which is beginning to give cause for concern. Unless new more environment-friendly fertilisers, herbicides and pesticides are developed, agricultural production could well begin to suffer. Problems of nitrates and run-off of pesticides have already been referred to. There are considerable opportunities for science and development of new technologies, which will have significant economic potential, particularly for export, to combat such problems. New approaches to research in

agriculture which were referred to in Chapter 6 are also releted to such issues. The problem of intensification in agriculture was discussed and the research areas relevant to this, for example, minimum tillage cultivation and low input farming.

APPENDIX II - INTERNATIONAL ASPECTS OF SCIENCE

1. The 1984 Annual Review of Government-funded Research and Development draws attention to and makes comparisons between countries in their patterns of R & D spending. Marked differences in expenditures between countries are exhibited as the figures below show, but the review comments that although such figures broadly indicate the nature of the balance of expenditures, they do not in themselves enable insights to be obtained of the reasons for and desirability of the balance for individual countries.

Government Funded R & D in OECD Countries in 1981
(% of GDP x 100)

	France	Germany	Italy	Japan	UK	USA
Agriculture, fisheries and food	5.1	2.3	2.0	6.4	5.2	2.7
Industrial Growth	11.4	12.5	12.2	3.1	10.4	0.4
Production of Energy	9.5	17.5	16.1	6.6	8.7	12.0
Health	5.8	4.7	1.8	1.5	1.5	13.8
Advancement of knowledge	31.8	48.7	21.2	28.1	30.0	4.6
Civil Space	5.4	4.8	3.8	3.0	2.7	16.9
Other (environment, transport, social, etc)	11.5	14.6	3.7	3.3	5.6	8.5
Total Civil ($ billion)	4.37	6.70	2.78	5.21	3.00	17.13
Total ($ billion)	6.96	7.34	2.97	5.34	6.26	35.55

(Source: Annual Review of Government-funded R & D, 1984)

2. Perhaps the outstanding feature of the expenditures shown is that US public expenditure on R & D, at 35.5 billion dollars per annum, is greater than the sum of all the R & D expenditures of the other countries listed, at about 29 billion dollars. Funding of civil R & D by the US Government amounts to some 17 billion dollars compared with 22 billion dollars for the other major OECD industrialised countries. If Japan is excluded, such US funding amounts to roughly the same as that of the four major European countries together. Expressed as a percentage of GDP, public R & D expenditure by Japan and Italy are considerably smaller than in the other countries shown. If the R & D spend by the private sector in the USA is of the same order of magnitude as that in the public sector, as it is in the UK, then the total R & D spend compared with that in other major industrialised countries is formidable and in terms of R & D coverage is one with which other countries cannot hope to compete.

3. Although the figures are not strictly comparable, because of differences in classification, for example, the USA funds basic research (advancement of knowledge) through `mission-oriented´ agencies, they do give a broad indication of the relative priorities of different countries. The USA spends a higher proportion on civil space than do other countries. Health research receives considerably more support in the USA than it does in other countries, although in the UK some medical research expenditure comes within the category related to `advancement of knowledge´. Apart from the USA, all the countries listed give the highest priority to public support for advancement of knowledge with Germany giving significantly more than do other countries. Germany also has the highest expenditure on R & D in the production of energy and other R & D areas concerned with the environment, transport, social and urban development. However Germany spends relatively little on defence R & D as do Italy and Japan. The country with a pattern and volume of spending on R & D most similar to that of the UK is France, which spends slightly less on defence and much less on agriculture but somewhat more on production of energy (nuclear programme) and environmental, transport, social R & D than does the UK.

4. Interesting as these figures are they do not give a picture of the details of science supported by other countries nor of the processes by which judgements on science are made. The SPRU study has provided some insights

into the latter and we consider these in the UK context later in the chapter. We discussed first the priorities for support of science in some other countries.

Scientific Priorities in other countries

5. At the outset of the exercise, we asked UK Science and Technology Counsellors in certain countries to obtain information on the science and technologies which those countries saw as important for the future. A considerable amount of useful information was received in response to this request, some which has been discussed in the SPRU report, but some additional points which are relevant to the study are worth drawing attention to.

Japan

6. Expenditure on research and development in science and technology in Japan is increasing at a faster rate than the general growth of the economy. In 1981/82 this amounted to 2.11% of GNP compared with 1.95% of GNP in 1980/81. The private sector provides a large proportion of this expendture, 73% compared to a Government share of 27%. Of R & D carried out in industry, 98% is funded by companies themselves. Applied and development research accounts for 86% of the total which has led the Japanese Government to increase its efforts to encourage more fundamental research. The most important expenditures are by the Ministry of Education (49%), the Science and Technology Agency (27%) and the Ministry of International Trade and Industry (12%). Research for technologies of the future is supported by both Government and the private sector. The Science and Technology Agency has introduced a special programme known as Exploratory Research for Advanced Technology (Annex 2), to help bridge the gap between basic research in universities and industrial laboratories. The Ministry of Education has taken measures to increase the number of joint industry/university projects.

7. Basic or fundamental research is increasing within the larger Japanese high technology companies. Hitachi Central Research Laboratories aim to spend 20% on basic research and will increase this in the future.

Similarly, most of the electronics companies have embryo research programmes for so-called bioelectronics. Hitachi is also studying DNA using electron holography. Many of Japan's best known ~~universities,~~ universities for example, Tokyo's Institute for Industrial Science and Institute for Solid State Research, receive numbers of temporary guest researchers from industry who are charged high fees.

8. The Ministry of International Trade and Industry (MITI) in Japan focuses on the next 10 years or so. The methodology used by MITI to forecast future technologies involves intimate discussions between industry, Government and universities. A new project often arises from discussions in trade associations or the Keihadren (which represents industry, Government and other sectors of the economy). Budget authority is only given on a year-by-year basis, but a global figure is introduced for the length of the project which can be up to 10 years. Projects have a fixed life-time which are strictly adhered to. Some 3 or 4 years MITI analysed its future technology R & D programme in terms of achieving three objectives; secure energy sources, increased standard of life, and new wealth producing industries. A programme based on the analysis known as the Basic Technologies for Future Industries Project is now well established. The MITI programmes aimed at R & D to provide the technologies for commercialisation in Japan in the next 10 years or so are summarised in Appendix III. Recently MITI have established a new project on bio-elements with £200 million support over 10 years.

9. Perhaps the main conclusion about the areas of science and technology which are expected to be commercialised in Japan over the next 10 to 20 years is that they contain few surprises. The only area of really speculative research is in computer technology and biotechnology, particularly genetic engineering. There is little mention of supersonic travel systems and limited interest in fast breeder reactors and fusion. In broader areas, mariculture is important in Japan in extending food resources. The long-term Credit Bank of Japan predicts high growth particularly in ceramics and biotechnology. Also there will be increased developments to improve living space conditions. In terms of their impact on Japan's future industrial prosperity, the most important technologies are likely to be:

Advanced robots and manufacturing systems

Fifth generation computer systems

Basic technologies in materials, electronics and optoelectronics

Biotechnology

Technologies for integrated digitalised network communications, including space.

United States

10. R & D in the USA is a large and profitable business as the following figures show.

Activity or Industry	Sales $ billion	1982	Profits $ billion
Fuel	486		25.3
Automotive	122		- 2.0
Chemicals	106		5.6
Food	85		3.6
Research and development	70		8.6
Computers	60		5.3
Electronics	53		3.0
Aerospace	49		1.7
Drugs	47		4.3

Many research laboratories in the USA both in the public and private sectors have not been slow to perceive the opportunities and income to be derived from R & D and a number of universities have industrial liaison programmes spanning all university departments. A major technological university, the Masachasetts Institute of Technology obtained $20 million in 1982 from selling its R & D to industry.

11. It would not be useful to consider in detail the funding mechanisms and

selection of scientific and technological research priorities in the USA; the reader is referred to the comprehensive analysis for us by SPRU which was published in the book `Picking the Winners´. As indicated earlier the total US Government R & D civil budget dwarfs that of any other country, consequently a broad range of institutional structures exist to develop policy, manage and organise Government funded R & D. The SPRU study concluded that longer term attempts in the USA to identify promising areas of science have met with a mixed response. At a national level, overall research forecasting was the responsibility of the Office of Science and Technology Policy (OSTP) who published five-year Outlooks, in the Annual Science and Technology Report to Congress. However a decision was taken to abolish the separate outlooks because of their failure to prioritise between different scientific areas and in future one chapter of the report would be devoted to an assessment of future trends and opportunities, together with their social and economic implications. In place of the Outlook, OSTP instituted in 1982 a series of annual `Research Briefings´ and although the production of such reports involves more industrial researchers, they tend to be dominated by `science-push´ considerations and are of variable quality depending on the composition of the panel which produces the report. The Research Briefing do, however, appear to have had more impact on policy making. Subjects covered by the 1984 briefings summarised in Annex 4.

12. In response to our invitation to provide information on the US approach, the UK Scientific Counsellor reviewed the major fields of science and technology in the USA and his report "Some emerging technologies in microelectronics and computing, materials, biological and chemical sciences in the USA" included at Annex 1. In most instances the technology is still in the emerging stages with many years of basic work still ahead, whilst others are somewhat more active. In most cases substantial progress in science and technologies and accelerating exploitation in marketable products is expected. From the OSTP Outlooks, and Research Briefing, and the report of the Scientific Counsellor, the broad themes which emerge from US science and technology are:

- changing perspectives on health care

- the faster pace of technological innovation

- the importance to scientific and engineering progress of the effective use of new communications technologies

- the emergence of research-based technologies

- the need to examine national policies in regard to research and development as a whole

- the quickening dissolution of traditional boundaries between the sciences and between science and technology

13. So far as the private sector is concerned, US industry is as well-served as any country in the world, including Japan, by organisations willing to provide forecasts and assessments of potentials of markets, science and technology. Thus there are large corporate institutes in both the public and private sector from whom companies can seek advice as well as large numbers of smaller consultancies of both a general and specialist nature. In addition, the databases available to industry are well-developed. Science Indicators is produced at a national level and consultancy organisations produce patent databanks and science citation indices.

France

14. Public research in France is commissioned mainly through the Centre Nationale de la Researche Scientifique (CNRS). The total overall CNRS budget for 1983 was of the order of 7 billion francs. There are seven major spending sectors and the following shows the amount each area received in 1983.

Research Sector	Total budget for 1983 (labour and materials - millions of francs)
Energy and raw materials	322
Materials	342
Biotechnology	321
Pharmaceutical	230

Electronics	110
Fine chemicals	168
Social sciences	50

15. In 1981, Programmes Mobilisateurs (PM) were introduced. These are defined as "mobilising" scientific programmes in order to prepare France for the world in the 1990´s. Seven programmes have been defined, of which four are orientated towards science and industry: rationale production and use of energy, biotechnology, electronics, industrial development (eg robotics). Three others were aimed at the political and social end of the spectrum. The PM´s were created to revitalise and create new industries, and the role of government is seen as facilitating the entry of research laboratories and industry into the programmes. Electronics and biotechnology have been the subject of major study reports and priority areas have been nominated. These are, in order of priority: development of a new, powerful, scientific computer (vector processor), a new module for mini and microcomputers, consumer electronics, VDU´s, man/machine interface, computer aided education, multiservice communications, cable systems, VLSI, CAD/CAM, word synthesis, electronic cameras, word processors, and machine assisted translation. In biotechnology, French and British plans are similar in that the development of new industrial processes is seen to be as important as the products themselves (eg new generation antibiotics, hormones from animals, interferon, synthetic blood, biopesticides, bio-fertilisers, amino acids, enzymes, etc).

16. The distribution of research workers in French industry is similar to that in British industry and is as follows: electronics 19.6%, aerospace 18.1%, automobile 12.6%, chemicals 9.4%, pharmaceutical 5.7%, information 4.8%, heavy-electrical 3.7%, mechanical 3.4%, rubber plastics 3.4%, metallurgy 2.2%, and others 17.1%. Information has been received from the UK Scientific Counsellor in France on a series of published articles which focussed on the prominent areas of French science and technology programmes. The subjects included advanced batteries, artificial senses, interferon, office equipment, seeds development, cancer research, organic semiconductors, fifth generation computers, "biotics", CAD/CAM, composite materials, robotics, transport research, and alternative fuels.

17. The SPRU report concluded that prior to about 1980, state agencies in

France appeared to make relatively little use of long term attempts to identify strategically important areas of science. However, since that time there has been increased enthusiasm for such activities, with the adoption of more systematic and broadly based appproaches, such as the National Colloquium, and the establishment of various forecasting units such as the Centre de Prospective et d'Evaluation (CPE) in the CNRS and the Centre des Systemes et des Technologies Arancees (CESTA) in the Ministry of Industry and Research. In contrast, it was suggested that the enthusiasm of industry for long term science and technology assessments had waned in recent years.

West Germany

18. West German R & D expenditure in 1981 was about £10 billion. To compare this figure with that of the UK or France is not meaningful because employment costs are higher in West Germany, but more personnel are employed in R & D than in UK or France. Roughly two-thirds of the West German government R & D budget is spent in industry, with the remainder going to universities and state-owned laboratories about equally. The Government provides R & D funding particularly for heavy engineering (including vehicles and steel) and electrical/electronics engineering but little to chemicals. Roughly about 20% of total research spending goes on basic research.

19. R & D in West Germany is supported by the Federal and State Governments, with the Federal Government tending to support industrial research and Federal States pure research. The current approach by the Federal Government is not to adopt a too dirigiste approach in setting R & D priorities, but where it sees a clear need to intervene it does so. Recent examples are massive support for the nuclear industry with the aim of decreasing dependence on imported oil, and support for R & D to try to overcome barriers to the use of new tecnology. In the university and pure science sectors, funded by State Governments, academic freedom to pursue science without Government intervention is keenly defended. The Federal Government has a wide range of measures to support research and innovation in industry, the different types of support are:

i. direct grant support for projects in key areas of technology

ii. non-project based support including capital/assistance and tax incentives

iii. support for joint and cooperative research facilities

iv. information and advice centres including facilities

In project support for industry, efforts are made to concentrate on key areas of research which will be important for the future health of the economy, or on developments in the wider public interest such as reduction in pollution, better access to and utilisation of raw materials.

20. The technical university system has been highly successful in promoting technology transfer, since there is close interaction between universities and industry in applied science, particularly engineering, and mobility of staff between industry and academics. However, rigidities in some parts of the R & D system have become apparent, in particular, the inability of the large science institutes and laboratories to adapt to new requirements. The problem is being addressed by encouraging them to take on tasks more relevant to current needs of industry and increase technology transfer. Also of concern is the fact that West Germany has a large deficit on foreign trade in patents fees and licenses, as does Japan also (in contrast with a surplus in the UK).

21. So far as scientific foresight in West Germany is concerned, SPRU reported that in respect of publicly supported basic research, initiatives were left to the scientific community and there was little in the way of foresight activites relating to Government-funded strategic and applied research, largely because of the mainly medium concerns of the funding bodies involved. A greater appreciation by German companies of long term assessments was noted, in particular, the willingness to use both internal systems and consultancies to assist in long-term corporate planning.

Other Countries

22. Information was also received on science and technology priorities in some

other countries. Thus China and Saudi Arabia place importance on support of R & D, but in areas of science relevant to their geographical and economic circumstances. On the other hand, doubts were expressed in an Australian report on whether significantly increasing support for R & D in new key technologies was a cost-effective use of resources for that country. A comprehensive survey is currently being carried out by the Science Council of Canada to identify emerging science and technology for Canada. The preliminary findings from the survey are shown in Annex 3.

GENERAL CONSIDERATIONS

23. Collaboration and cooperation in international science activities is of considerable advantage to smaller countries or those unable to fund scientific research on the scale of major industrialised countries. So far as the UK is concerned, collaboration internationally allows our scientists access to a much wider range of scientific facilities than could be afforded nationally. Other advantages are to be gained, such as, the cross-fertilisation of ideas, and production of a more stimulating scientific environment in which to work. In some cases, duplication of effort is avoided by collaboration. The base of qualified scientists and engineers might be broadened by international cooperation. At the technological level, some countries, for example, France and Japan, encourage their scientists to participate in scientific exchanges and collaboration, with long-term commercial and other aims in view.

24. Another aspect of international collaboration is that related to `gate-manship´ in particular science areas. Thus participation in international collaboration often allows a greater gain in scientific activity than if the same investment was made in UK-only scientific programmes, and as such might be regarded as a means of gaining more scientific output for the amount invested. Although some investment is required, a level of credibility and recognition can be established sufficient to enable a watch on the change in scientific activity to be maintained which will be of assistance in determining national priorities.

APPENDIX III - COLLECTED COMMENTS ON SCIENCE AND TECHNOLOGY IN THE UK

1. Maximisation of the number of science areas which hold potential opportunities depends on a variety of factors, not the least of which is the organisation of and attitudes to science. We discussed in Part II the way that the products of science have come to permeate practically all aspects of life today, and the relationship between economic activity and progress, and the rapid exploitation of scientific advances. We have also referred to the fact that the United Kingdom carries out somewhere in the region of 5% of world research activity and the need therefore to select carefully those areas of science for national support which can make the maximum contribution to international competitiveness. In certain key areas particularly in some physical sciences, recent evidence indicates that, the quality of United Kingdom R & D has decreased in recent years. Also, at some international conferences on important scientific subjects at the leading edge of exploitable science , the UK presence is minimal whereas in other areas of less importance the meeting may be dominated by United Kingdom representation. During the course of our consultations with companies and institutions, views were expressed about the organisation of and attitudes to science in the United Kingdom, and in this chapter we have brought these together more as a record of opinions, frequently of assertions or prejudices which we do not necessarily endorse but consider that they should be recorded because they are part of the picture of UK science which we have been seeking to obtain.

Availability of Science

2. Many of the companies and institutions consulted pointed to some unsatisfactory aspects of the national R & D effort; one or two companies expressed disillusionment with publicly-funded R & D in relation to innovation and industrial technology and several made constructive suggestions to improve the effectiveness of R & D of the country as a whole. Attention was drawn to imperfections in the mechanism, with respect to public sector R & D for interesting scientists in the areas of science of economic significance. There was also some lack of flexibility in funding arrangements with respect to publicly funded research. However. such views invariably diminish the value of areas of science which are

culturally important, and that although the criterion of economic uti[illegible]y is vitally important, it cannot be the sole one. The structure of the board and committee system in some Research Councils still exhibited rigidities and although modifications had been made to co-opt members from other disciplines there was a perception still that past interests have a greater influence on decisions than some areas of importance for the present and future. Scientific areas also became more fashionable or less fashionable, and it was necessary for those concerned with the management of science to maintain a watching brief on scientific fields in order to monitor and respond to real changes taking place.

3. The view was expressed that in universities, the ability of academics to choose their topics of research was of importance to obtain the best and most forward-looking scientific research. But research funding bodies had a responsibility to support research in their fields of interest and a suitable balance was necessary between purely reactive support for university research and support for particular areas of interest. Greater effort was needed to contrive a more appropriate balance of activities in the scientific fields developed in universities.

4. With the recent changes in the financial position of universities, the tendency in universities now was to maximise short-term economic gains from research activities. The result was that less science which had broader applications was carried out and the results of science programmes were becoming less widely available, since their accessability was restricted to those who had commissioned the work. Because of the interest in short term gains, universities were becoming unsighted in one their primary missions which was to seek the advancement of knowledge. In the past, it had generally been assumed by the scientific community that British research was of the highest calibre and second to none; this was often not now the case. Major companies increasingly commissioned research in those parts of the world where the best research was being carried out. The effects of the financial constraints had been patchy, in some universities, it was the most able scientists who had been affected. It was not expected that these trends would be reversed in the short-term and this would have implications for the timescales on which science and technology could be developed.

5. A phenomenon of research in parts of the public sector R & D was that the quality of a scientists research output tended to decline after 6-8 years. This related to the capability of managing research discontinuities. Universities in the USA had a larger number and higher turnover of research professors who attracted research funding to the university, which covered professorial expenditure, and brought prestige to the university. Major companies could not afford to allow stagnation in their research laboratories and continually redeployed scientists and technologists as research programmes changed.

6. The availability of science was dependent on the size of the scientific community in a particular discipline or field. The rate of communication of information through that community was also important. Parallels were drawn between the information technology area in the USA and in the UK. The much larger size of the IT community in the USA meant that a greater level of activity occurred there than in the UK. The nature of US society and culture played a key role also in the rapid communication of information and exchange of ideas. Market size was also important in relation to science and the UK would need to find a niche which gave it a strong competitive position; it was not possible for the UK to cover all scientific areas and to do so in competition with the larger scientific communities could be damaging. There were strong economic grounds for selection in the placing of R & D resources.

7. In areas like biotechnology or information technology, there was good expertise, relatively, in the universities and Research Council institutes in the underpinning basic science areas, and the country should capitalise more on these. Opportunities existed in terms of the "elegance" of research for which the UK had historically enjoyed a high reputation. For example, in biotechnology, by bringing together science at the molecular and cellular levels with physical and electronics science, the "elegance" of the British scientific approach could have advantages. It was necessary, however, to identify the niches suitable for this approach and then put resources into those areas. It was suggested that the approach should not too all-embracing in relation to niches identified.

8. There was a need also for industry to be more risk-taking in the exploitation of science which was available. Spin-off from research was

inadequate and there were insufficient numbers of small and medium si[illegible] companies to exploit research. Industry should marshal resources of knowledge and capital more quickly in order to take advantage of fast-moving technology. The new biotechnology industry was not sufficiently aggressive in the UK, and needed to look more to world markets for exploitation. In general, greater perception of the timescales of change and improved ability to manage change was required by the industry. Industry had not ~~so far shown~~ responded sufficiently ~~response~~ in assisting with the research effort in the public sector which they claimed was vital to their interests.

9. It was suggested that insufficient attention is paid to direction-setting in the technology strategy of companies; technical direction was often carried out at the project manager level. Technology tended to be developed in the UK by a "product champion" approach whereas greater success could be achieved by a broadly planned strategy as in Japan. Technological directions in the UK were often not brought together to provide a clear focus in planning ahead; in Japan judgements were based on greater consensus and coherence in order to bring together different technical directions supported by a more factually based methodology. In general, companies in the UK do not seize opportunities even when they had been perceived. There is a tendency to rely on traditional markets for technology than to look for new markets and develop new technologies for new markets. The inertia in companies often initiated against the development of the enabling technology. Adherence to a traditional technology which might be dominating a particular market sector could inhibit development of new technologies and render the sector vulnerable to penetration by new technologies developed abroad.

Implications for Funding

10. In a country of the size and with the sources if the United Kingdom complete freedom of choice in research was not possible, which meant that some important science fields were bound to be neglected. Several of those consulted suggested that a way forward in improving research in universities would be the formation of "centres of excellence" in particular subjects at a small number of sites. These would then tend to act as a focus to attract relevant industry involvement and collaboratorion, and would concentrate expertise. Such concentration would

also reduce funding problems, as equipment became more sophisticated and expensive, costs for university research were becoming increasingly difficult to meet over a large number of locations.

11. It was difficult also to obtain a strategic overview of the scientific areas of excellence in relation to the broad sweep of publicly funded R & D. With the exception of the MRC, generally, it was not possible to obtain from the Annual Reports of the Research Councils a clear idea of the distribution of quality in the research supported. It was represented to us that it was not possible possible to compare quality of effort in research in scientific fields supported by one Research Council with those supported by another. Research funds of both Research Councils and universities should be concentrated in the areas of scientific excellence. Thriving, forward-looking university research departments could be identified, and such departments might form the basis for development of niches in science. Resources in the universities were spread too thinly, and such an approach would increase the effectiveness of the resources which were available. The Netherlands had demonstrated that limited resources were not a hindrance to scientific success by encouraging and channelling support to particular science niches. However, the scientific community in the UK was not sufficiently aware of the opportunities which such an approach offered, and a re-orientation process was required in university research in particular.

12. Some sections of industry were concerned with research in complex multi-phase, multi-component systems but problems relevant to such systems were rarely tackled by the universities. Industry was often able to maintain links with high calibre individuals in the universities whose research was highly regarded, but, in general, there was a tendency for universities not to work on the more complex research problems. Industry frequently had no choice but to tackle complex problems for the sake of commercial interests, and universities might be encouraged to tackle the difficult scientific problems but important, that the universities did not become involved in the day-to-day problem-solving activities of industry or feel that their main purpose was to serve industry.

13 It was not generally perceived that a large central national research institute was required. UK industry already had access to the large

international institutes, and there were plenty of institutes in the UK. Neither was it considered that the UK was at a disadvantage from the lack of a very large industrial laboratory like those of some major US companies. A major problem was to attract the best graduates to the industrial laboratories. The leading companies did obtain good students for their laboratories but in general industrial laboratories had a poor image in the UK. Industrial research centres in the UK could be made more attractive at a cost, but conditions and benefits in the public sector would still attract good students. Industrial research in the US was attractive because of the prestige attached to such research, and generally greater risks were taken in order to secure greater rewards. It was suggested that graduates were too willing to remain in university research because the pressures involved were less. Industry had a problem that too many good scientists were attracted to the public R & D sectors, and lost good research workers for a variety of reasons to the nationalised industries and Government laboratories.

14. Almost all those consulted believed that it was necessary to maintain a strong intellectual science base in the UK. Science was under-capitalised in the universities and the University Grants Committee should consider how departmental structures and responsibilities could be rationalised and the balance of teaching and research both between and within universities managed. The scientific community should give a clearer message about the criticality of scientific research for the future. At the present time neither academic research workers nor the organisations which supported them had a clear perception of the role which they should play.

15. Some basic sciences relevant to industry should be given suport by DTI over the above that given by the Science and Engineering Research council. DTI tended to assist industry rather than science so that continuing support was given to industries which had ceased to be competitive whereas the science upon which new industries would be based were not given adequate support. The physical sciences needed more support from Government in order to stay at the forefront internationally.

Importance of Interdisciplinary Approach and Collaboration

16. Both industry and the institutions considered that a greater

interdisciplinary approach to science in Government supported research was required. We have discussed such an approach in Part II in more detail. Universities in particular were too compartmentalised and their structures were an obstacle to interdisciplinary activities. The reasons for this were historical and financial in nature, and also related to the career system in universities. A greater research interaction within universities would lead to a greater flow of scientific and technological information from academia to industry and vice versa. Major companies made possible significant technological advances by assembling mixed discipline teams, and at one time the University Grants Committee had done so by earmarking funds but the practice had ceased in recent years. Advancement of knowledge within disciplines would still be necessary and this would be assisted by infusions of knowledge from other disciplines. A related aspect was the location of subjects in university departments. In the USA, for example, there was much greater interest in the search for new solid state materials since research in such materials was located in chemistry departments, whereas, in the UK, interest was located in physics departments so that research focussed mainly on solid state theory and not materials, and was therefore commercially less valuable.

17. The interface between sciences, which were not catered for in "strategic" research, were important, and in this respect, the SERC co-operative scheme approach was a promising development. More joint activities between the different committees and scientific panels of the Research Councils were required. For example, neutron beam physics could interact with biological science; chemistry might have a major impact in the field of applied optics which might itself be used in the elucidation of cell processes. There was a complex matrix of science involved in information: in large-scale integration, the gates could well be chemical switches, and a breakthrough in the techniques for forming uni-molecular layers could have major consequences for many areas of science. In the USA, colloid chemistry was linked closely with chemical engineering. Chemistry/materials science/chemical engineering were inadequately linked in the UK, partly because the teaching of inorganic chemistry was too narrow. There was an area of science of interest to many companies, concerned with the scientific nature of perception, which lay at the boundaries between physical science and psychology. A range of research activities was carried out in relation to visual phenomena, but in the

areas of sensory, olfactory, and tactile perception and imagery littl work was undertaken. The science itself had scarcely been conceived, nor was there a scientific language to describe phenomena.

18. Considerable scope existed for collaboration between companies and between private sector and public sector in research activities. It was becoming increasingly difficult for companies acting alone to match the research effort of overseas competitors. Some areas were more suitable than others for co-operative research ventures at the pre-competitive stage; such areas included catalysis, materials science, plant biochemistry, immunology, and toxicology. Funding of electronics research by the US Defence Department had had considerable spin-off for US industry generally, but there had not been similar advantages to British industry from work in electronics supported by the Ministry of Defence; there had been little impact of such work on consumer goods electronic companies. The philosophy of developing technology according to a targeted selling price which might initially result in some losses to be recouped later was alien to many UK companies.

Scientific Education

19. We heard a number of views on the general educational aspects of science. In the broader context, the uptake of technology requires a more technologically informed society and the scientific community should have greater ability to translate scientific ideas for the rest of the community. More effort should be put into accessing and disseminating information. The education process in the UK must keep pace with the rate of change in education occurring in other parts of the world. Comments were made that most subjects in schools, colleges and universities were taught on the basis of "taxonomy" than of "application" but a change in approach would be difficult because teachers and text-books were themselves based on the former system. The commercial sectors express concern that many graduates are too narrowly educated in particular subjects. On the other hand, it is also suggested that greater use could be made by industry of the education of the scientists which they employ to obtain a greater understanding of industrial processes in order to make advances in such processes and develop new processes.

20. Concern was expressed about education at the graduate level, in particular that teaching methods in universities were not advancing and that the approach in universities was too syndicalist in nature. Shortages of good graduates existed in some key scientific disciplines. The numbers of students entering courses in electronics had fallen in recent years; chemistry departments were producing the wrong type of graduate for industry and knowledge of industry at the teaching level was lacking. At the postgraduate level, compared with the USA, too little guidance is given in the training of PhD students; such students receive insufficient coursework and are required to specialise at too early a stage of their training.

21. Education and employment in engineering had received attention in recent years but some dissatisfaction with progress in these areas was still apparent. The academic system did not encourage Engineering Departments in universities to direct their teaching towards equipping those who will have a basic comprehension of the breadth of the practical tasks which they will wish to face in the future. The emphasis in university engineering education remained in preparing students for academic research and higher degrees. Some industries on which the UK's future prosperity depended (particularly manufacturing) were not good at attracting and keeping the best young people. The "image" of engineering in schools and universities had not improved and UK companies gave too little responsibility and too little reward to engineers. The hypothesis that the best engineering graduates were not as interested in applied research as in "doing things", compared with scientists, needed testing. Expectations should be matched by industrial opportunities and commensurate rewards. Too few companies and individual managers were willing to entrust major tasks to young engineers and accept that occasionally mistakes were made. Without changes in job opportunities, manufacturing industry would not attract, develop and keep the high-calibre people essential for this vital wealth creating sector.

22. Advances in science would depend increasingly on interdisciplinary collaboration (we have drawn attention to this in some detail in Part II But greater perception was required both in universities and by Research Councils of the opportunities presented by collaborative science. The concentration of resources in a particular area, also, distorted the

overall pattern of funding and affected support for other areas. Some areas became attractive because of the "curiosity factor" and frequently a pressure builds up for manpower and resources to move into those areas but the temptation to over-react to such pressures should be resisted and a balanced judgement on the relative requirement against other demands should be made. A problem was perceived of research by both universities and Research Councils being carried out too independently. The Research Councils through their Board and Committee structures allowed the peer review system to dominate the directions of research which they funded in universities. More inspired leadership was required in Research Council institutes to encourage greater collaboration.

23. Research work in both public and private sectors required scientists with ability to think creatively around problems; both problem "identifiers" and problem "solvers" were needed. Scientists of different disciplines would increasingly be required to work together but the university approach to training tended to produce graduates with an "isolationist" attitude towards science. Other countries seemed more able to produce graduates who could adapt better to working in multi-disciplinary teams. Compartmentalisation in university teaching was becoming an urgent issue which required consideration.

24. The biological sciences were poorly served by the university system. Biology was a 'safe' option in GCE 'A' level examinations at schools, which was attractive to pupils. The courses in universities tended to be relevant to non-industrial areas of biology such as ecology and environmental sciences which often drew the best students and were oversubscribed, but the job opportunities in biology were poor. Industry was unable to identify suitable academic partners with which to undertake collaborative research in the basic biochemical and cellular models in biology. Academic weaknesses in plant physiology and plant biochemistry had been exposed; too much effort in universities went into botanical and zoological taxonomy. The polytechnics tried to compete with universities in advanced aspects of biotechnology, for example, gene manipulation, recombinant DNA techniqus, etc, but their effort should be aimed more at the applied aspects such as processing, downstream technology, etc. The polytechnic role was seen more in educating people for jobs.

25. In the medical field, imbalances in education and research were also apparent. Insufficient academic interest was displayed in microbiological disciplines and bacterial chemotherapy was inadequately covered in universities; several university chairs in bacteriology remained unfilled. No tradition existed in the UK of a major university department with interests in infectious diseases, whereas the USA had several important university departments with such interests. Insufficient publicly supported research was carried out in neurobiology and in clinical pharmacology; the process of ageing was not a subject which was amenable to the type of research approach in industry. Immunology and disorder prevention were also areas which deserved more attention from the universities. More opportunities existed for collaborative research in the field of cancer than in other areas of medical research. An initiative was needed nationally to open up a debate on collaborative medical research. The scale of effort in subjects such as molecular biology, and immunology, was perceived in spite of the success of British scientists in these fields, still to be inadequate in relation to the industrial opportunities they promised.

Further considerations

26. There was a general impression in the scientific community that the standard of research has fallen off in recent years. The decline appeared to predate recent restrictions of funding. Whereas it has generally been assumed in the past that the best research was carried out in British universities, this was often not now the case. The mechanisms by which universities affected change in the direction of research were obscure; yet universities must evolve and accept new directions. Teaching in universities was often too narrow, and could be enriched by incorporating in the teaching methods an awareness of the wider fields which scientific disciplines were applied. Such an approach would attract students and encourage them to consider broader scientific problems.

27. An analysis of contributions to journals and conferences over recent years in relation to academic solid-state physics and chemistry has shown an alarming perceived loss in the achievement and status of UK science in these areas at a time when other leading scientific countries such as Japan, West Germany and France are increasing their efforts in this area.

It was speculated that this picture may apply to other key areas of science also. A SERC panel report (Report of a Panel to Review Trends in the Support of Physics ("Vinen" Report) - March 1982) expressed concern about the health of physics as measured by various indicators, such as the low number of SERC studentships and fellowships sought by university departments, and low completion rates for higher degrees of physics students. Impediments to encouragement and support of mainstream physics were identified in the representation and structure of SERC Council and Boards. Thus, both nuclear physicists and astophysicists, which together represented about one third of the total physics community each had a separate board to look after their interests and were represented separately on the Council. Whereas the remaining two-thirds of the physics community were not represented directly on the Council nor had a Board to look after their interests. SERC were in the process of acting on the Vinen report with a view to redressing the balance in research activities, representation and support in UK physics.

28. More recently the national debate about priorities in physics research has been widened by the decision of the Advisory Board for the Research Councils in March 1964 to review jointly with the Science and Engineering Research Council, United Kingdom participation in high energy particle physics. The review was prompted by the considered view of the Board that the objective of supporting all first class people and ideas required reassessment in view of recent overriding financial and economic constraints; it was therefore necessary for the Board and Research Councils to consider "whether complete withdrawal from some area of science would release resources that could be better developed in other areas and in making the whole system more flexible and responsibe to new opportunities". Two particularly costly areas identified were high-energy particle physics and satellite-based astronomy. The imbalance in support with respect to the latter has been mentioned above and commented on by those consulted during the course of this study; and the extent to which the UK can be committed to research in disciplines of astronomy has been the subject of further review recently. We note with approval that one of the terms of reference of the review of high energy particle physics is to consider the implications of reallocation of the resources currently used to support such physics in whole or in part to other areas of science, and look forward to the report on the review in the early part of 1985. We

have observed earlier that UK science tends to be funded on an "all or nothing" basis, whereas what is required is a proper balance. We would hope that in future the funding bodies can make more considered judgements on the proper balance of support for scientific areas.

29. The view was expressed by several of those consulted that the social sciences such as sociology, psychology, behavioural science would be of growing importance and wider relevance because of the insights which they could provide, for example, to industry and the wider R & D community. In the case of industrial companies, such insights could be used to form judgements on the strategy of competitors, identify market niche and size, and develop views of the future. Behavioural science, for example, could play an important role in understanding and catalysing the interactions of the natural sciences. The Economic and Social Research Council should be central to development of such roles for the social sciences and other organisations such as the Technical Change Centre would have a part to play.

30. Some of the issues which have been raised with respect to organisation and attitudes to scientific research in the United Kingdom have been considered in the advice published in September 1984 by the University Grants Committee to the Secretary of State for Education and Science in "A Strategy for Higher Education into the 1990s". The advice acknowledged the responsibility of the universities to ensure that resources for research are allocated and managed to best advantage. New general principles for the allocation of resources were suggested based on greater selectivity in allocation, better planning and management within universities, and increased interaction between the universities and UGC in devising detailed research plans. But planning of research and funding allocations in universities cannot be carried out in isolation from the wider needs and of the requirements of funding bodies such as the Research Councils. A more balanced and interdisciplinary approach to teaching in the universities will affect their research portfolios which will have consequential effects and require more careful consideration by the Research Councils of the areas of science which they support both in the universities and in-house. The organisation of higher education is currently under review by the Department of Education and Science, and we would hope that the issues which have been raised in comments to us and

the key statements of the UGC will be given careful consideration and a bold, imaginative initiative taken in the Green Paper to be pubished later this year.

31. Two further reports are also relevant to the considerations discussed here. The first is the report of a working party of the ABRC on "The support given by Research Councils for in-house and university research" and the second the joint ACARD/ABRC report entitled "Improving Research Links between Higher Education and Industry". It is some time since both reports were published and it was hoped that ~~we would hope to see~~ responses to them would be made in the near future.

APPENDIX IV

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APPENDIX IV

THE COMMON CRITERIA

(see Appendix I, para. 7)

1.* Councils and their Boards/Committees/Groups are invited to use the criteria listed here to discuss and compare relative benefits. Whenever practicable, reference should be made to objective data in support of the assessment (eg demographic data; social costs; relevant government expenditure etc.) in relation to the cost of the research.

Scientific Policy Criteria

(1) Excellence of study field
 Where benefits are attributable to a high proportion of the research being intrinsically of high intellectual value.

(2) Excellence of the research workers
 Where benefits are attributable to the exceptional quality of the individuals or teams to be employed in the activity.

(3) Pervasiveness of the activity
 Where benefits include the impetus to advances in other and related fields of science in addition to the primary field.

(4) Social and/or economic importance
 Where expected benefits arise from the work being directed to supporting social or economic aims.

(5) Significance for the training of scientific manpower
 Where benefits will include training and experience for scientific research workers.

(6) Educational importance
 Where benefits will include a contribution to education.

(7) Significance in maintaining national scientific prestige
 Where benefits will contribute to national reputation.

Management Criteria

2. A set of selected management criteria are also offered. These apply to the consideration, from a management policy point of view, of alternatives which have already been assessed on the scientific policy criteria.

A. Efficiency of operation
 Where improvements in organisation and/or plant would lead to a general increase in efficiency.

B. Obsolescence
 Where the maintenance of a capability (at whatever level of activity) requires replacement within the Forward Look period of a major item of obsolescent plant or equipment.

C. Timing
 Where a start on a new or increased activity within the Forward Look period is critical if the expected benefits are not to be lost or much reduced.

D. Dependence on Science Budget Support
 Where there is likely to be limited support, national or foreign, available for work related to the activity except the Science Budget.

E. Availability of scientific manpower
 Where an activity attracts priority by virtue of greater availability of scientific manpower for it (or its execution is constrained by lack of it).

F. Scope and limits of redeployment
 Where the priority accorded to an activity is conditioned by difficulties or opportunities of redeployment

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* Extract from instructions to Research Councils, 1975 Forward Look.

APPENDIX V

ORGANISATIONS CONSULTED

Beechams Pharmaceuticals
British Petroleum
British Shipbuilders
British Telecom Laboratories
Ford Motor Company
Guest, Keen and Nettlefold
Glaxo
Imperial Chemical Industries
Standard Telecommunications Laboratories
Unilever

Royal Society
Fellowship of Engineering
Conservation Society

NCB Coal Research Centre

Science and Engineering Research Council
Medical Research Council
Agricultural and Food Research Council

Ministry of Defence
Department of Health and Social Security
Department of Trade and Industry

ANNEX 1

SOME EMERGING TECHNOLOGIES IN MICROELECTRONICS & COMPUTING, MATERIALS, BIOLOGICAL AND CHEMICAL SCIENCES IN THE USA

COMMENTS BY DR A R COX, COUNSELLOR FOR SCIENCE AND TECHNOLOGY,
BRITISH EMBASSY, WASHINGTON, USA

Microelectronics and Computing

Silicon chips are getting smaller, faster and smarter and the single chip computer, combining logic and memory function, is in view. The Intel ATC51 chip is some way down this path. A 512k bit dynamic RAM has been announced and there are proposals for a 4 Mb chip by 1990 and 16 Mb by the end of the century. The Defense Department VHSIC programme will encourage this trend towards miniaturisation.

Attention is being given to molecular switching elements based on one dimensional polymers, eg trans-polyacetylene (CH)x and sulphur nitride (SN)x. These may be manufactured by lithographic and vapour deposition techniques, chemical synthesis or biotechnical synthesis. These chips could achieve gate densities of 10^{13} - 10^{18} /cc and exhibit 100-1000 fold increase over current processing speeds. Once available, they could be incorporated as 3-d array processors and have a revolutionary impact on small intelligent robots and medical applications.

Emphasis is also being given to chip packaging and interconnection. Technology is being developed that is compatible with automated assembly at integrated circuit and systems level, supports a high pin count and is sufficiently flexible for use in many different applications.

Microprocessors will become increasingly powerful. By 1990 it is expected they will have 1-10 megabytes of memory and contain many utilities in chip firmware (eg word processor, electronic mail, transaction processing, view data and teletext). Parallel processors using large numbers of micros will be established for both military and civilian applications. Already there are examples of 256 Z80A processors working in parallel in the US; there is talk of connecting 1 million together.

The trend in microcomputers towards "integrated" machines comprising hardware and bundled software with a "user-friendly" environment using spreadsheets and a 'mouse' for input will continue. The user will interact with a text editor which will double as an operating system. A change in the next 5-10 years will be the changeover to comprehensive speech input and output. Networking will become more pervasive - both LANs and X25 interactions.

Large fast computers from CRAY, Trilogy and CDC will continue to be used extensively in research, benefiting from the advances in microelectronics. There are developments in supercomputers that can handle very large amounts of data in communications. Wafers functioning as a PCB, electro-optic communication links on chips, visual interpretation and speech understanding, natural language processing and parallel array processing will undergo major advances. Anticipated advances in artificial intelligence theory are expected to result in new systems capable of a hundred thousand interferences per second. Data-base machine architecture offers a ten fold improvement over current machines. A new user-interface should be based on speech/image recognition.

Chips and processors will not be alone in benefiting from technology. Improvements will also come in portable hard discs, bubble memories, battery-backed memory, disc cartridges, streaming tapes, laser printers/plotters, flat screen displays and voice synthesisers.

Software development and maintenance now accounts for more than 75% of the installation costs. Efforts continue on making programming easier and more productive but the benefits appear to be marginal. To improve the situation by an order of magnitude needs far more radical thinking. It will be interesting to see if the vast sums now being invested to develop new structures between the users and the programmes, will provide this.

Materials

Because of its pervasive influence on all fields of technology, materials research is being given particular attention. A National Center for Advanced Materials Research is proposed for Berkeley, California where a combination of high energy physics techniques in the hands of academic and industrial researchers is expected to expose a new generation of materials with unexpected combinations of properties. Products of earlier research, such as amorphous materials and electro-active polymers, are currently being exploited in the high technology end of the market. As costs decrease and familiarity grows with these materials, their incorporation in high volume consumer durables is expected. Research and development into composites and structural ceramics will reduce the dependence on vulnerable strategic materials for aircraft, automobiles and gas turbines. Amongst these materials are those with high modulus incorporating graphite fibres, silicon nitrides and carbides in metal, polymer and ceramic matrices.

New applications are seen for liquid crystal polymers, high temperature polymers, lithographic polymers and polymer adhesives. There are rigid chain polymers with high strength to weight polymers which could revolutionise aircraft and automobile structures. Further improvement in the processing of electronic materials is expected, a product of an improved understanding of atomic interactions and kinetics. There will be improved materials for optical fibres, photon detectors and solid state devices which offer further advances in computers, telecommunications, artificial intelligence and sensors. Surface science advances will result in improved catalysts and corrosion resistant alloys. There is renewed interest in rechargeable batteries, using new electrochemical systems with organic liquids, crystalline ceramics and thin films of ionically conducting polymers.

Further opportunities for developing new materials are offered by the prospect of a reliable and continuous presence in space. Space station, currently in concept stage, is expected to be approved within the next twelve months, prodviding a substantial facility for materials processing. It is envisaged that under microgravity conditions, substantial increases in electrophoretic separation of pharmaceuticals can be achieved, opening up the prospect of new pharmaceutical products. The sterile environment is ideal for manufacturing high value processing equipment for use in the semiconductor industry. A recent review suggests there are also commercial opportunities in the biological processing of high performance catalysts, gallium arsenide crystals, biologically active membranes, new plastics, bone replacements and metal reforming.

Another space based activity which will continue to grow and foster new industries and services is remote sensing. The planned developments in sensor technology will provide a wealth of data on the atmospheric troposphere, biosphere and the earth itself. Once globally collated and interpreted, the owners of the information will have unique opportunities for identifying new markets and offering new services in agriculture, economic material extraction, routing and long term environmental predictions.

Biological and Chemical Sciences

In the biological field the progressive application of genetic engineering techniques to an increasing number of areas will lead to commercially valuable advances in the public health, agricultural, waste disposal and the synthetic chemical and energy fields. The hugh number of potential areas of application will ensure that biotechnology continues as an important expanding technology throughout the next 10-20 years. The basic science and technologies required for these developments are already present or are being researched in well-funded programmes both within industry and government.

Within the public health field, the increased knowledge of the chemistry of cell metabolism and how the bodily system operates is already leading to a revolution in medicine. The potentials in diagnostics are considerable (whether for monoclonal antibodies or DNA probes) and are already being well-exploited. Genetic engineering is also generating new drugs and treatments or alternative methods of making existing drugs (eg insulin, interferon, growth hormone, tissue plasminogen activator). In the next 5-10 years, vaccines can be expected for venereal diseases (eg Herpes), general diseases (eg hepatitis, flu and polio) and some of the major tropical diseases (eg malaria). In the longer term recombinant DNA may offer cheaper routes to a range of amino acids, vitamins, enzymes and hormones. Synthetic blood products will be marketed and a "universal" blood may be a possibility.

The greater understanding of protein chemistry and of the very detailed mechanisms determining how molecules exert their functions, offers thepossibility of major changes in pharmacology. Up until now pharmaceutical research has relied heavily on natural products which are screened for some biological activity. In future it will be possible to design (via CAD) the drug molecule to achieve extremely specific and optimised effects. To achieve this it is necessary to specify the surface properties of the macro-molecule, to predict the sequence of amino acids which would lead to that particular configuration, and then to code and express the appropriate gene for the protein's production. Before such 'designer' drugs are a reality, further research is needed to predict the folding of a protein of known amino acid sequence and to fully understand the role of different surface features of the folded molecule. Other means of increasing existing drug activity and specificity will be developed in the 5-10 year period via links with carrier molecules which improve penetration of the cell wall. Links with monoclonal antibodies will allow specific cells to be targetted. In the 10+ year time scale, developments may include human gene screening and limited therapy for some specific forms of cancer.

In the field of medical technology, the availability of drugs (cyclosporins) which suppress the immune response may lead to a substantial increase in the public's expectation of successful transplants, leading to a demand for organs which cannot be met from human sources. The demand for the development of artificial organ (eg kidney) replacements will thus intensify. Here it will be necessary to combine electronics, mechanical engineering and biological materials (eg nerve/electrode interfaces) for an implantable device. Progress in linking nerves to electrical controls (technology-push)has already been made and will combine with market demand to increase expenditures on prosthetics. Other areas of biology/electronics such as biosensors have already been identified and funded.

So far the self-replicating ability of DNA and cells has only been used to produce molecules. However it is theoretically possible to make structures (living and non-living). Possible areas here include membranes and the "biochip" as a molecular computer, although the chances of the latter (if feasible) having the necessary robustness for an electronic device appear remote.

The application of genetic engineering to Plant Agriculture is some years behind the medical field and will require continued research into gene identification, insertion and expression before commercially valuable developments are made affecting yield, product composition, disease/pest resistance, growth rate, weather tolerance and N-fixing ability. This will take such developments into the timescale of interest to Horizon. Earlier applications are expected in the animal health field of vaccines, growth hormones, etc. Genetic engineering of specific traits in animals and subsequent cloning will also take place.

New macro-molecules offer considerable potential in the development of new materials as well as in the biologically active areas of application listed above. Again a better understanding of the links between molecular structure and physical/chemical properties would lead to an ability to design a molecule to produce a desired material specification. Chemical and enzyme catalysis has moved from art into science, and a potential exists for significant progress in this field both in better efficiencies in chemical reactions and in the design of new catalysts to create new chemical molecules. Techniques of CAD can also be usefully applied in these areas.

Science and Technology Department
Washington DC

September 1983

ANNEX 2

NOTE FOR ACARD

FUTURE TECHNOLOGY IN JAPAN

COMMENTS BY DR C C BRADLEY, COUNSELLOR FOR SCIENCE AND TECHNOLOGY, BRITISH EMBASSY, TOKYO, JAPAN

1. Expenditure on research and development in science and technology in Japan is increasing at a faster rate than the general growth of the economy. In 1981/82, this amounted to 5.4×10^{12} yen or 2.11% of GNP, whereas in 1980/81, the figures were 4.7×10^{12} yen and 1.95% of GNP (annex 1).

2. The private sector provides a large proportion of this expenditure, 73% compared to a Government share of 27%. Significantly, of R&D carried out in industry, 98% is funded by the companies themselves. Applied and development research accounts for 86% of the total which has led the Japanese Government to increase its efforts to encourage more fundamental research.

3. Government expenditure in 1983/84 is estimated to be 1.45×10^{12} yen and is divided amongst several Ministries (annex 1). The most important are the Ministry of Education (49%), the Science and Technology Agency (27%) and the Ministry for International Trade and Industry (12%). Research for technologies of the future is supported by both Government and the private sector. The Science and Technology Agency has introduced a special programme known as Exploratory Research for Advanced Technology (annex 2), to help bridge the gap between basic research in Universities and laboratories in the private sector. The Ministry of Education and Science has recently taken new measures to increase the number of joint industry/University projects (28 in the first stage - see annex 3). Many of Japan's best known Universities, for example Tokyo's Institute for Industrial Science and Institute for Solid State Research, receive large numbers of temporary guest researchers from industry who are charged high fees.

4. Basic or fundamental research is also increasing within the larger Japanese high technology companies. Hitachi Central Research Laboratories aim to spend 20% on basic research and will increase this in the future. Similarly, most of the electronics companies, such as Toshiba, Sharp, have embryo research programmes for bio-electronics which could be a technology for the 1990s. Hitachi is

/also

also studying DNA using electron holography to extend their expertise into future new areas of technology.

TECHNOLOGY FORECASTS

5. In Japan, many Government and private institutions undertake technological forecasting, for example the Science and Technology Agency, MITI, Mitsubishi Research Institute, Hitachi Research Institute, Nomura Research Institute. The methodology used by these organisations is being reviewed for ACARD by Mr Irvine of Sussex University and will be the subject of a special report by him.

SCIENCE AND TECHNOLOGY AGENCY

6. Probably the most important recent exercise on forecasting for the 1990s and beyond has been made by the Science and Technology Agency using a Delphi procedure. STA has an extensive report on this in Japanese which was published at the end of 1982. Abstracts from it are available in English and these are summarised in the paper in annex 4. The STA assessment not only identifies future technologies but also attempts to forecast their likely achievement stage for exploitation. The Delphi exercise is of course a very uncertain one (as STA officials admit) but the results have considerable interest as representing the views of a large number of experts in Japan. The fields concerned reflect a broad view of what the Japanese people would like to see achieved. They concern particularly energy, health, environment and natural resources, but as annex 4 shows, in many sections there is considerable detail about future technology, as in the case of robotics.

7. In chronological order for realisation in Japan, these are some illustrative examples from the english language abstract :

1989	Prospecting for agriculture, fisheries, forrestry and minerals by satellite.
1990	Large-area amorphous silicon solar cells (although this exists currently, it is much too costly).

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1991	Measurement of positions at sea using satellites.
1992	Long-range weather forecasting. Robots for use in difficult and dangerous environments.
1993	Commercial uranium centrifugal separation process for uranium enrichment.
1994	Technologies for the safe disposal of radioactive waste. Food processing technology using genetic engineering. Super large-scale integration electronics with 10^8-10^9 devices per chip.
1995	Drilling technologies for subsea oil at more than hundred metres depth. 3-dimensional electronic memory devices. Physical and engineering laboratory in space.
1996	Marine and weather observation using satellites and buoy robots.
1997	Collection and refining manganese modules. Large-scale nuclear reprocessing plant. Seabed observation for forecasting earthquakes.
1998	Breeding of plants and animals by mesoplast fusion. Direct aluminium refining technology.
1999	Chemical agents for treating stomach and lung cancer.
2000	Purification of lakes, rivers etc.
2001	Drugs for treating anteriosclerosis.
2002	Disaster prevention to minimise earthquake damage.
2003	Commercialisation of making steel with nuclear power heat.
2004	Technology to convert cancerous cells to normal cells.

/2005

2005 Superconducting material with a critical temperature greater than 77K

2006 Earthquake prediction for large and medium-scale earthquakes with a one month timescale.

A report summarising STA's own research programme is included as annex 5.

MINISTRY OF INTERNATIONAL TRADE & INDUSTRY

8. MITI's forward look focuses on the next 10 years or so. It reflects more than STA's a more immediate imput from industry. The methodology used by MITI to forecast future technologies involves intimate discussions between industry, Government and University. A new project often arises from discussions in trade associations or the Keidanren (which represents industry, Government and other sectors of the economy). Proposals are put to MITI who may have made informally the initial suggestions and after discussion between interested parties, and particularly the Finance Ministry, general agreement on an appropriate research and development programme is reached. Budget authority is only given on a year-by-year basis, but a global figure is introduced for the length of the project which can be up to 10 years. In most MITI projects, such as its well known one on very large scale integration, the project has a fixed life-time which is usually strictly adhered to. When a project is launched, a formal management framework is set up to coordinate projects in industry and Government laboratories. The management system reflects the role played by the participants and that of advisory committees. An example is shown in annex 6 for the Electronic Devices project.

9. 3 years ago, MITI analysed its future technology R&D programme in terms of achieving 3 objectives for Japan; secure energy sources, increased standard of life and new wealth producing industries (annex 7). To achieve these, a matrix of objectives was set up which is aimed at providing the basic technologies. These are new materials, biotechnology and new electronic devices. This programme is now well established and is known as the Basic Technologies for Future

/Industries

Industries Project. The cost to MITI is £300m over the next 10 years.

10. In addition to these programmes, MITI has a number of large scale projects which also involve Government and industry, and for which the time horizon for realisation and possible commercialisation is the next 5-10 years. These include :

Sunshine project (new energy sources, coal liquefaction etc).
Moonlight project (energy conservation).
Flexible manufacturing system using lasers.
Fifth Generation Computers,
Advanced robotics.) (being established)
Remote sensing with satellites.)

All these include technologies which are likely to be realised and possibly be commercialised in the next 5 to 10 years. More detail about the individual projects is described in annex 8.

FUTURE TECHNOLOGIES IN NEXT 5-10 YEARS

11. The MITI R&D programmes provide the best view of what are likely to be the technologies for commercialisation in Japan in the next 10 years or so. In summary, these are likely to include :

(a) Electronics/semiconductors

Super-fast GaAs and Josephson Junction switches. 3-d integrated circuits. Electronic elements for use in hostile environments, eg radiation. Superlattice devices (quantum well lasers).
Integrated optics.
High definition TV.
Low cost read and write laser discs.
20% efficient low cost solar cells.

(b) Advanced Manufacturing

Intelligent robots 3rd generation.
Factory 'computer' concept which will include management decisions.

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Automation in sewing industry.
Flexible manufacturing systems with lasers.
Robots used for hazardous environments.
Machine Tools with ceramic parts for high precision.

(c) Biotechnology (annex 9)

Bioreactor technology to reduce energy consumption in chemical processes.
Large-scale cell cultivation.
Recombinant DNA for hormones etc and for production of bulk commodity chemicals.
Interferon
Monoclonal antibodies.

(d) New Materials (annex 10)

Fine ceramics for engines, prostheses, sensors, electronics etc.
Super alloys for gas turbines.
Composite materials for high temperature, high strength applications.
Polymers with special properties such as electrical conduction.
New superconductors for power cables.

(e) Space

Microgravity experiments and technology to produce new alloy materials.
New launch rockets.
Remote sensing technology, computer software development.
Satellite clusters, rather than one single large satellite.
High power, low power consumption computers for space.

(f) Communications (annex 11)

Integrated networks digitised.
Video and telephone networks integrated.
Home Facsimile.
Tele-conferencing.
Local area networks.
High definition TV.
Satellite TV.
Portable telephone.
Man-machine voice communication.

/(g)

(g) Computers

Fifth generation computers, parallel processing (annex 12).
Artificial intelligence.
New memory elements and parallel processors using VLSI.
Superfast computers.
'Optical' computer (1990s).

(h) Energy

Cheap solar photocells.
Coal liquefaction (commercial).
Fast breeder reactors (commercial >2000).
New aerogenerators.
Stirling engines.
New energy efficient products and processes.
Advanced heat pumps (absorption type).
Advanced batteries for storage and for vehicles.
Fuel-cells for electric power, eg solid electrolyte and molten carbonate.
Gas turbines for use with difficult fuels.
Energy reduced processes in steel and aluminium extraction.

(i) Transportation (annex 13)

Linear motor transportation, magnetic levitation.
New subway systems (energy efficient).
Electric vehicles using advanced batteries.
Superconducting motors for ships, using sea-water as the conductor (2000).
Fan-jet STOL aircraft (1990s).

(j) Food

Mariculture.
Biotechnology.

(k) Health

Artificial heart.
Lasers-scalpel and direct chemical treatment.
Portable artificial kidney.

/Implanted

Implanted hearing devices.
Guide robots for the blind.

MINISTRY OF EDUCATION

12. The Ministry of Education has the largest Government R&D budget which is mostly spent in Universities. The projects mainly concern basic R&D with some development with industry as noted above. The major research areas include energy, space, nuclear physics, life sciences, ocean science and earthquake studies. There are also, as expected, a very large number of research programmes which are relevant to the technologies listed above which are likely to be important in the next 10-20 years, but it would be impractical to list them.

CONCLUSION

13. The preceding paragraphs have given some indication of the areas of technology which are expected to be commercialised in Japan over the next 10 to 20 years. They do not include any real surprises which is perhaps characteristic of the Japanese approach. The only area where a fair degree of leaping in the dark occurs is in computer technology and bio-technology, or more particularly genetic engineering. There is little mention of supersonic travel systems and only limited reference to fast breeder reactors and fusion. In broader areas, mariculture is important in Japan in extending food resources. Also, there will be increased developments to improve living space conditions.

14. In terms of their impact on Japan's future industrial prosperity, the most important technologies are likely to be :

Advanced robots and manufacturing systems.
Fifth Generation Computer systems.
Basic technologies in materials and electronics and optoelectronics.
Biotechnology.
Technologies for integrated digitalised network communications, including space.

/15.

15. Finally, as perhaps some confirmation that Japan's R&D is on the right lines, the Long Term Credit Bank of Japan has produced a forecast of sales for new technology-based industries for the period up to 1995. This shows that there is expected to be phenomenal growth, particularly in ceramics and biotechnology. However, like all such projections, they must be treated with some caution.

C C Bradley

Dr C C Bradley
Counsellor
Science and Technology

12 October 1983

ANNEX 3

ERGING SCIENCE AND TECHNOLOGY FOR CANADA – PRELIMINARY FINDINGS OF A SURVEY BY THE IENCE COUNCIL OF CANADA

Unit on Emerging Science and Technology

MICROELECTRONICS AND THEIR APPLICATIONS

- Microelectronic Devices----------------------------------Improved Devices (e.g. higher Density, More Powerful, Cheaper, Faster) Fault Tolerant Chips Power Control Chips
  - CMOS - Gallium Arsenide
  - Microprocessors - ICs for Adverse Conditions
  - VLSI (Higher Density) - 3 Dimensional ICs
  - Superlattices
  - Memory (Bubble, etc.)
  - Chipmaking (X-Ray, Electron Beam)
  - Quiterons (Superconducting)
- Optoelectronics
  - Optical Fibres--Communications
  - Semiconductor Lasers
  - Optical Computing
  - Transducers
- Computing & Computer Hardware-------------------------Modems, Cryptography, Printers, Plotters, Security Devices
  - Digital Signal Processing
  - Image Processing
  - Superfast Computers
  - Interactive Home Computing-----------------Shopping, Banking, Information Retrieval, Work, Education, Entertainment, Voting and Opinion, Home Security and Health Alert, Energy Control.
  - Optical Discs---------------------------------------Storage, Education, Entertainment
  - Display Technology (e.g. Flat) Portable Computers
- Software & Software Development
  - High Level Language
  - Logic Arrays
  - Computer Modeling (e.g. Toxicology, Climate, etc.)
  - CAD/CAE/CAM/Robotics/Flexible Manufacturing-------Automated Inspection, Remote Failure Diagnosis
  - Artificial Intelligence--------------------------Machine Translation
    - Knowledge-Based Systems----------------------Expert Systems
    - Speech Recognition & Synthesis---------------Voice Command
    - Machine Vision---------------------------------Flexible Manufacturing
    - Fifth Generation Computer
    - Semi-Automated Software Production
- Communications
  - Satellites - Remote Sensing-----------------------Weather, Mapping
    - Navigation
    - Direct Broadcast
  - Video Conferencing
  - Cellular Radio (Mobile Telephony)
  - Digital Telephony
  - Microwave
  - Earth Stations
  - Facsimile
- Bioelectronics-----------------------Biosensors, Biological Computing
- Sensors------------------------------Monitoring and Automation
- Control Systems----------------------Consumer, Industry, Medicine, Transport, Agriculture
- Prosthetics-------------------------Muscle Stimulation Devices
- Medical Detection and Devices---------Positron Emission Tomography (PET), Nuclear Magnetic Resonance (NMR)
- Electronic Office
- Digital Audio------------Entertainment
- High Definition TV
- Videotext

Unit on Emerging Science and Technology

BIOTECHNOLOGY AND ITS APPLICATIONS

- PRODUCTION TECHNOLOGY/VECTORS
  - Fermentation Technology---------------Improved Yeast Strains
  - Large-Scale Cell Cultivation-----------Production Techniques
  - Bioreactors---------------------------- " "
  - Tissue Culture & Micropropagation-----Plant Improvement
  - Hybridoma-----------------------------Medical Diagnostics & Treatments
  - Biotechnology Instrumentation

- PRODUCTS
  - Single Cell Protein-------------------Livestock Feed Supplements, Food
  - Fuels (e.g., Alcohol, Methane) and Feedstocks From Biomass--------------Economic, Renewable Fuel & Chemical Supply
  - Polymer Production--------------------Biodegradable Plastics
  - Chemical Production-------------------Catalysts, Fine Chemicals, Etc.
- Biosensors & Bioelectronic Devices
- Recombinant DNA:
  - In Medicine
    - Monoclonal Antibodies--------Diagnostic, Preventative and Therapeutic Products
    - Insulin (Human)
    - Interferon, Interleukins
    - Human Growth Hormones
    - Gene Therapy
    - Pharmaceutical Production----Hormones, Enzymes, Vaccines, Peptides, Neuropharmaceuticals, Etc.
  - In Agriculture
    - Nitrogen-Fixing Plants
    - Stress-Tolerant Plants
    - Plants for Hydroponics
    - Improved Crops & Livestock
    - Embryo Transfer
    - Veterinary Pharmaceuticals
    - Bacterial & Viral Biocides
  - In Aquaculture
    - Improved Species
  - In Silviculture
    - Improved Tree Species
    - Biocides

- PROCESS APPLICATIONS
  - Food Processing
  - Waste Treatment---------------------
    - Degradation of Organic Wastes
    - Contaminant Recovery
    - Metal Recovery
  - Bioleaching----------------------------
    - Mining (Metal Extraction)
    - Coal Desulphurization
    - Metal Recovery

MATERIALS

- Plastics/Polymers
  - Structural
  - Conductive
  - Piezoelectric
  - Elastic Materials
  - Membranes

- Superconductors (Cryogenic)
- Optical Fibres
- Semiconductor Materials (Polycrystalline & Amorphous)

- Metals
  - Steels
  - Aluminum
  - Powder Metallurgy
  - Advanced Alloys
  - Glassy (Amorphous) Metals
  - Memory Metals
  - Metal Matrix Alloys
  - Brazing Alloys

- Ceramics
  - Fibre Reinforced
  - Metallic Glasses
  - Solid Electrolytes

- Glass
- Paper (Plant Fibre)
- Structural Fibres
- Composites
- Cement & Concrete
- Refractory Materials
- Fibre Reinforcement of Metals
- Lightweight Materials
- Substitutes for Harmful Materials (e.g. Asbestos)
- Renewable Materials
- New Fabrication Techniques
- Finishes & Surface Deposits
- Thin Films & Adhesives
- Bearing Materials

ANNEX 4

RESEARCH BRIEFINGS 1984

Summary of the 1984 Research Briefings prepared under the supervision of Committee on Science, Engineering and Public Policy (COSEPUP), a joint committee of the US National Academies of Science and Engineering and the Institute of Medicine.

1. *Computer Architecture*: Research directed toward increasing the speed and capabilities of computers through innovative hardware design and software optimization, including parallel processing.

2. *Information Technology in Precollege Education*: Research directed toward identification of special opportunities for use of new information technology in precollege education offered by recent work, notably in the cognitive sciences, artificial intelligence, hardware, and analyses of the strengths and limits of currently available and anticipated devices.

3. *Chemical and Process Engineering for Biotechnology*: Long-range fundamental research directed toward developing new reactor concepts (immobilized-enzyme reactors and continuous large-scale cell culture systems) and developing new unit operations for manipulating and purifying fragile macromolecules in highly complex product mixtures.

4. *High-Peformance Polymer Composites*: Research directed toward synthesis of high-strength, high-modulus polymers and polymer composites for structural applications, including examination of relationships between microstructure and performance within single-phase materials, and relationships between surface characteristics and interfacial properties in multiphase composites.

5. *Biology of Oncogenes*: Research directed toward enhanced understanding of the genetic characteristics of cellular and viral oncogenes, the process of activation of oncogenes and its relationship to chemical/environmental carcinogenesis, and the nature of oncogene products and how they subvert normal orderly cellular growth and development.

6. *Interactions Between Blood and Blood Vessels (Including the Biology of Atherosclerosis)*: Research directed toward enhanced understanding of the interplay between blood constituents and the blood vessel wall, ranging from molecular and cellular interactions to the role of injury and subsequent disease.

7. *Biology of Parasitism*: Research directed toward enhanced understanding of how parasites establish and maintain relationships with their hosts and the consequent disease processes, including examination of:

- cell membrane phenomena;
- intermediary metabolism;
- life cycle and development changes in vectors and in hosts;
- immune system and other protective responses and their underlying genetic and regulatory mechanisms; and
- related opportunities to develop vaccines, pharmaceuticals, and biological controls.

8. *Solar-Terrestrial Plasma Physics*: Research directed toward understanding the interconnected physical processes responsible for the injection, transport, energization, and loss of plasma from regions on the sun, in the solar winds, and in the earth's magnetosphere.

9. *Selected Opportunities in Physics*: Research directed toward enhanced understanding of the following promising areas of physics: physics at the laser-atomic frontier; relativistic plasma waves; physical properties of deliberately-structed materials; biomolecular dynamics and intercelluar cooperativity; cosmology; and nuclear matter under extreme conditions.

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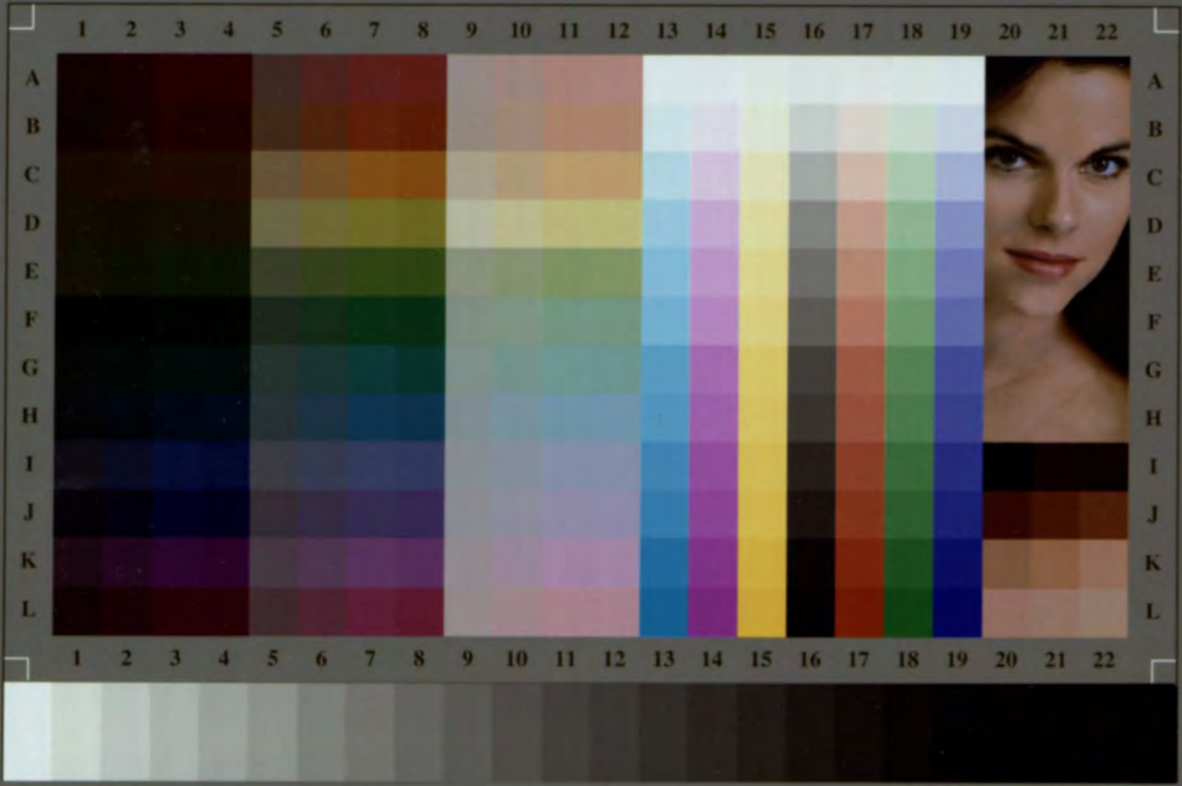

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