Emerging Thematic Priorities for Research in Europe

Working Paper

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Note:

This report is a working paper of the IPTS. It is meant to provide substantive input to a debate on the priority themes for European research.

It provides highlights of the major themes that are emerging for research in Europe drawing on expert judgement, recent national foresight exercises and the expertise of IPTS and its partners, especially the ESTO network.

It is not an official Commission position nor proposal, and is not meant in any way to be a selection of priorities for the future Framework Programme.

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Executive Summary

This document contains an analysis of possible priorities for European Research. The analysis has been carried out as one contribution to assist the European Commission's Research Directorate General (DG Research) in preparing future policy discussions and proposals. The analysis was conducted over the period mid-September to the end of November 2000. It drew on several sources of information and expertise. First of all, a high level expert group - including some Commission officials - was set up for the project and played a central role, meeting on three separate occasions. In addition, a series of background papers based extensively on the large body of recent national foresight exercises were drafted by sectoral experts in IPTS and its partners, mainly from the ESTO network of national institutes engaged in technology analysis and foresight[1] (see the full list or participants and contributors in Annex).

The task of identifying research priorities was approached from two complementary directions. First, *top down* by identifying a set of European-level challenges that raise research requirements. Second, *bottom up* by approaching the identification task from the side of research opportunities that can be identified when starting from key scientific and technological developments. Both approaches were guided by the idea that the research priorities would be characterised by novelty (new driving trends or new research opportunities) and increasingly cross-sectoral issues (greater complexity and interaction between problems and a rise of transdisciplinary research).

Throughout the process the emerging research priorities were tested for European relevance against a set of criteria that was also elaborated in the course of the project. This list falls into three main categories: areas where research support is warranted at a European level, areas where there is some explicit policy relevance and areas in which the international position of Europe is at stake. The detailed list is discussed in Chapter One.

The results of this whole process are the research priorities that are presented in the two main chapters of the report - in broad terms in chapter two and in a good deal more detail in chapter three.

Five European Mega Challenges

Chapter Two presents **five 'European Mega Challenges' where S&T research can play a significant problem-solving role**. In overview, these are:

I. **A Knowledgeable Europe to Compete in the Digital Economy**: *harnessing together the old and new economies, knowledge systems for production and services, and life-long learning*

There is a growing importance of "intellectual" labour in both new and established sectors of the economy. This transition could not happen without new information and communication technologies (ICTs), but its success rests essentially upon having the human know-how to benefit from the new technological opportunities.

Four research requirements are identified to build ***competitiveness in the knowledge economy***: improving the science and technology base; stimulating

[1] These are available in draft form as downloadable working papers on the project web-site http://priorities.jrc.es/

creativity and entrepreneurship; improving organisational innovation and performance; and understanding human factors in the use of new technologies.

Building a ***learning society*** focuses attention on the educational issues where the basic challenge is to build learning organisations and systems. New learning technologies and tools are essential but insufficient without innovations in organisational processes.

II. **Sustainable Development**: *precautionary research, ensuring sustainability and security in the face of increasingly complex issues such as global climate change, food safety and information security that require assessment, management and mitigation.*

Many of the serious risks facing human society today stem from the consequences of advanced technology and economic development. Complex challenges are impacting on the environment (e.g. global climate change, threats to bio-diversity), health (e.g. BSE, food safety) and social compatibility (e.g. threatened privacy by using genetic information or ICTs).

Such challenges call for three different lines of research. First, it is necessary to investigate and understand the nature of the risks. Second research is needed into how to avoid or to neutralise the effects of these risks. Third research is needed that helps to provide a rapid reaction that can mitigate problems once they have started to unfold.

III. **Lifelong Health and a Healthy Society**: *the challenges of living longer, better and at an affordable cost*

Europeans are living longer with high chances for a good quality of life throughout. We also want to live in a 'healthy society' away from physical threats, and excessive stresses. But as a result we face a rising societal bill. The challenge is to find an affordable ways to continue the upward pathway for human development.

The research requirements tend to be driven by the need for more cost-effective and higher quality health care systems. Research will be particularly needed to underpin the shift to preventative health care regimes and to create a safer and more humanised environment. Breakthroughs in techniques will also be very important, especially through applications of new research into gene technologies and cellular biology offering, for example, possibilities for new cancer treatments, vaccines, interventions against hereditary conditions.

IV. **Mobility and Energy**: *integrated and low emission approaches to transport, urban development and energy systems in an enlarged Europe.*

In the interlocking areas of mobility and energy, 'problem pressure' has increased over recent years giving rise to sustainability challenges such as CO_2 emissions, energy security, and safety. At the same time the growth and increasingly integrated transport systems of Europe face increasingly complex problems of traffic congestion that affect the air and ground transportation of both freight and passengers.

Both energy and transport are complex issues requiring systemic/ interconnected and long-term approaches. The research requirements reflect this need for system change. In energy, two of the main promising pathways – the hydrogen economy and decentralised energy supply based partly on a range of renewable resources - imply restructuring and a partial reconfiguration of the supply system. In transport, meeting the twin demands of economic growth and transportation demand will rest upon a broad range of technologies including ICT-based traffic demand management, service innovations such as intermodal mobility chains as well as vehicle improvements such as lighter materials and new propulsions systems.

V. **Building Europe**: *enlargement, European citizenship, public confidence and raising awareness of European issues*.

Europe will face many new challenges in the coming years. These include: enlargement; globalisation; changing values and lifestyles; cohesion issues related to different levels and rates of development; the accommodation of new migrants; the search for adequate governance models and the need to maintain the trust and confidence of citizens; increasingly shared security issues related to regional conflicts and instability; growing transborder crime.

These challenges raise many European-level issues. These relate primarily to understanding the processes at play through the creation of better information and databases, and social science research into the issues at stake. However, main technological requirements also result in the areas of trust and security as well as language and cultural conservation technologies.

Ten Key Science and Technology Areas

Chapter Three takes the consideration of research themes to a deeper level by synthesising together the research implications of the Mega Challenges with those that were generated from a bottom up consideration of the most important Science and Technology areas.

From this, **ten areas of science and technology where world-class competencies and exploitation capabilities must be developed and maintained** was produced**.**

These are presented in two sets. The first set, which we call **'demand driven'**, comprises the research themes that directly derive from the Mega Challenges.[2]

Demand Driven S&T themes:

I. Knowledge Sciences and Technologies

These define some of the principal research fields that underpin Europe's shift to a competitive Knowledge Society. They lie mostly in organisational, human factors and soft technologies research. They are application orientated with the research and technological systems largely being produced or at least heavily customised at the point of use. Important application areas include learning, new media and defence and security technologies, but all business sectors and types of organisations large and small increasingly rely on knowledge-development, enhancement and exploitation techniques. Research themes here are to a significant degree dependent on applications of Information and Communication Technologies (see S&T Theme IV below).

[2] We have kept these separate from the more generic challenges (considered in the second set below) to draw out explicitly the connections to the Mega Challenges, even though there of course many interconnections between the two sets of research themes (which gives rise to a degree of overlap and repetition).

Europe's future competitiveness depends upon the wide availability not only of end user skills but also of knowledge technology professionals.

II. Health Sciences and Technologies

The changing structure of European society and lifestyles points towards new health-research requirements. More elderly people means closer attention to gerontology and assistive techniques. Rising health-care expectations and costs point towards a heavier concentration of research on preventative health care, looking at high performance health systems and e-Health delivery. Greater mobility and changes in patterns of life also raise challenges in the form of new and re-emerging diseases.

Underpinning these societally driven health agendas will be a set of new medical techniques including Gene Technologies (see S&T Area V), tissue engineering and cellular biology, biomaterials and biomechanics. These generic techniques will also open up new opportunities for research on problem focused health issues such as the search for new cancer cures, treatment of orphan diseases, and the epidemiology of new and re-emerging diseases and anti-biotic resistance.

III. Technologies for a Sustainable Economy

A broad range of technologies and research are implicated here relating to three main fields.

Firstly **sustainable production and consumption** depend upon research into new socio-technical systems for balanced growth supported by techniques for the elimination of waste production from value generation through closed product cycles (re-use, recycling separation, maintenance and repair technologies), as well as more generic designs and modes of sustainable production, distribution and consumption. Also important are incremental developments in the reduction, recycling and treatment of waste, and minimisation of pollution.

Second the **management of natural resources** at a global level mainly refers to reducing emissions and the use of fossil fuels through new energy sources, new vehicle technologies as well as organisational innovations in transport and energy services, often based on telematics.

Third, research based on **monitoring, modelling and mitigating** environmentally adverse effects of technological progress on complex natural systems at both local and global levels, and on ways of integrating across systems which operate at different levels. This involves technical issues of risk management, safety, assessment of health effects modelling and control, in relation of pollution, ecosystems, climate, traffic and mobility but also more transdisciplinarity especially in areas such as socio-economic research into models of friendly environmental policy and links with health and education.

IV. Social Sciences in support of Building Europe

The challenges of building Europe call on research from both social sciences and humanities to provide insights and support. Especially important are forms of work that transcend disciplinary boundaries and which move towards integrative pan-European analysis.

Research Fields would include governance models, values research, the conditions for multi-cultural tolerance, European social models, cohesion, criminology, (cultural) consumption. In addition, it will be important to build up the social research infrastructure and toolbox: i.e. data-bases, data collection, information networks, common educational programmes, comparative research, benchmarking, participative methods, prospective analysis.

The second set of S&T areas is called **'cross-cutting enablers'** because they are of generic importance, often underpinning many other technologies. They thus provide an essential capability for future developments. **These are the technologies in which competences are required in order to maintain the position of Europe as a technology leader**.

V. Gene Technologies

The completion of human genome sequencing looks set to radically change the pharmaceutical paradigm from "bio-chemistry" to "pharmaco-genetics". At the same time, research in plant and animal genetics will be the base of our future agricultural production systems, reducing environmental problems and increasing yields. Developments in bio-informatics (data management tools, to store, access and analyse biological data) look essential to carry these projects forward.

Particularly important **gene-techniques** include: proteomics (the mapping of protein expression for disease control), transgenic animal models and plants, molecular epidemiology (for tackling multifacotral diseases), pharmaco-genetics (for more targeted treatments). Important **research tools** include: gene sequence and proteins structure databases; algorithms for analysing sequences and predicting protein functions, sub-cellular process modelling.

VI. Information and Communication Technologies

Capabilities in Information and Communication Technologies (ICTs) underpin almost all the other technology areas. Maintaining key competencies in ICT enablers, therefore, is essential to maintenance of a leadership position in most other fields. Three main technological dimensions can be identified as structuring the path of ICTs: the *ubiquity of computing*, the *ubiquity and seamlessness of communications* and a highly enhanced level of functionality in the form of *Intelligent User Interfaces*.

Research fields support these three interlocking strands. Miniaturisation and the rising ubiquity of computing indicate research on new paradigms for **computing** including hybrid nano-micro devices and greater use of bio, chemo, optic and silicon domains. In **communications** bandwidth requirements alongside demands for integrated channels (i.e. fixed and mobile web). This indicates a need for fully optical networks, seamless interconnection and ad-hoc configurability. As regards interfaces, rising demands will be placed on cognitive and human systems modelling and developments in hands free technologies (speech and pattern recognition).

Full ubiquity will only be achieved if breakthroughs can be made in dependability of software systems (self-organising software, component-based software and libraries), and security and trust technologies. Ubiquity also requires supporting breakthroughs in the material substrates of ICTs (smart materials, nanomaterials) and the peripherals (displays, biosensor systems, ambient energy).

VII. Advanced Materials

New materials are also strategic enablers for almost all other technology areas They provide the basis for innovations in system technologies such as transport, energy, defence and aerospace.

Two issues seem particularly important for research. First is sustainable materials that entails research to limit use of matter and energy, to generate low waste, and guarantee ecosystem compatiblity - based on renewables and biodegradability. Also of concern is to raise the recyclability of increasingly complex multi-material products and systems. Second, smart, intelligent materials, constitutes a generic materials research trend dictated by increasingly sophisticated requirements of new cutting-edge devices and products from construction to aeronautics, agri-food to biomedical implants. It covers many very fast moving and highly multidiciplinary fields which are crucial to business competitiveness in many sectors.

VIII. Nanosciences, Nano- & Precision Technologies

Nanoscience is an emergent transdisciplinary field drawing on physics, chemistry, medicine and biology, materials sciences and engineering. Application prospects range from nanoelectronics, artificial antibodies, new lasers, millimetre wave components, nano-porous filtering, hydrogen storage, fuel cell membranes, catalysts, nanodispersions for coating and hardening, layers for LCDs, antireflex surfaces and photovoltaics. ,.

Although seen as having great potential, commercial applications of developments in nanoscience are mostly long-term and depend on some very fundamental developments in atomic level assembly: custom designing of new molecules, and molecular architectures with novel macroscopic properties; the building of combinations of lateral with vertical atomic scale structures; the integration of components into systems and the scalability and reproducibility of laboratory-level demonstrations.

IX. Complexity and Complex Systems

The rising issue of complex problems and systems is strongly flagged in a number of the Mega Challenges (especially Sustainable Development and Mobility and Energy) and again in some of the other S&T areas (Knowledge, Environment, Health, ICTs). Typical features of complex systems are their often large number of components, the multi-level and multi-actor character of the phenomena in question, their dynamic and non-linear behaviour, the time-criticality of actions, and the inherent uncertainty and unpredictability of their future evolution/transformation.

Research issues include the basic understanding and management of complex systems in the wide range of different application areas; the development of generic tools and components to enable the design of new complex systems; and the development of an appropriate computing infrastructure (including data retrieval and system monitoring).

X. Fundamental Science

The final crosscutting enabler, fundamental sciences, was strongly identified in the work as an area that is essential to European research. It is an underpinning area of research for Europe both as the basis of future and emerging technologies and in order to tackle societal challenges. However, the area is not further developed in the current document. Although it is very important that fundamental scientific research should gain the benefits of European level economies of scale and scope, this area more than any requires a more flexible approach driven. Perhaps it is better to leave at least one area open to be defined by bottom-up by curiosity driven research or responsiveness to new opportunities that are not yet known.

Chapter 1 - Introduction

This paper discusses and analyses possible priorities for European Research. It represents one contribution to assist DG Research in preparing future policy discussions and proposals, following the publication of the Commission's guidelines for future EU research activities, "Making a Reality of the European Research Area."[3], itself a follow-up to the launching communication of ERA by the Commission in January 2000.[4]

The overall objective of the project to identify important themes for European level research was achieved under considerable time pressure through three rounds of expert workshops supported by background analysis of recent national foresight exercises undertaken by IPTS and its partners mainly from the ESTO network.[5]

In the first workshop the experts mapped out two generic sets of potential priorities for research. These were derived in two ways. First by approaching the priority-identification task from the societal challenges. Second, by reversing direction and approaching the identification task from the perspective of science and technology opportunities and development. These main issues were elaborated in more detail in smaller working group sessions.

The second workshop discussed how best to structure the resulting issue areas, and from these, what research themes might emerge that are appropriate to the criteria regarding 'European added value'. As guidance for this work, attention was continually made to corroborative evidence from national Foresight studies on the strategic importance and completeness of coverage of the issues identified. However, it is worth mentioning that the available Foresight evidence had two major deficiencies for the task, both of which were reasons for running an expert-judgement based project. First, the national foresight priorities are not directly related to the European level issues – they relate to the strategic issues facing the individual countries. Second, many of results from the most recent round of Foresights were not available when the exercise was launched. Thus, experts from each of these activities were drawn into the work in order to access their fresh knowledge and insights.

In addition, the project was guided by the principles that priorities for European research should be characterised by:

- The notion of **new trends** or imminent **trend-breaks** as drivers of new challenges, problems or opportunities, and which thus demand novel research effort in terms of new fields, activities or new combinations of existing ones;
- Responsiveness to the growing **transdisciplinarity of S&T**, and therefore, its use as a filter to identify some of the most fertile and demanding areas of research.
- The growth of **multisectoral** issues and bottlenecks, where in an increasingly interdependent economy, developments in one sector are enabled or hindered by developments in another.

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[3]Ref COM (2000) 612 "Making a reality of The European Research Area: Guidelines for EU research activities (2002-2006)" 4 October 2000

[4] Ref COM (2000) 6 "Towards a European research area" 18 January 2000

[5] See Annex for: the lists of experts participating in the workshops, the IPTS/ ESTO contributors to the background reports; on-line links to the background reports and to a list of main foresight reports consulted.

The resulting structure was the series of five societal 'Mega-challenges' that are described in Chapter Two. These are major items of European concern that cannot be ignored in any plan for European research co-operation. From these a set of thematic research areas are suggested.

Methodologically, it was also necessary to identify research themes from the perspective of scientific and technological opportunities. This perspective is better tuned to factors such as emerging fields, the implications of growing transdisciplinarity, the potential exploitation of new breakthroughs, and so on. Thus a separate exercise was carried out in the expert workshops to identify these themes.

Of course, many of the S&T themes generated were the same as those derived from the societal challenge driven research approach. For example post-genome biotechnology and renewable energy technologies emerged in both cases.

IPTS then synthesised the resulting list of key S&T areas to remove major overlaps and to capture the most significant themes emerging from the work. These are presented in Chapter Three in two parts. The first part, which we call demand driven, comprises the research themes that directly relate to the Mega Challenges. The second part, which we call cross-cutting enablers, are research themes of such a major significance (particularly as generic underpinning technologies) that Europe should investigate the need to work together to launch common or co-ordinated research projects in these areas.

Box 1 IPTS European-relevance criteria

Research support

1. Large-scale high-visibility projects
2. Building critical mass and exploiting economies of scale
3. Development of mutual learning and knowledge sharing
4. Encouraging a long-term horizon
5. Tackling complex issues
6. Bridging gaps in the innovation system

Policy links

7. Direct link to new & existing EU policy
8. The issue addressed has an inherently transborder nature
9. Support for the building of Europe
10. Protecting individual citizens
11. Developing public confidence

Performance and International position of Europe

12. Building on strengths
13. Developing future leadership in critical areas

The European Dimension

Before moving on, it is necessary to explain the approach taken to test the European-level relevance of the results. The criteria described below were developed by the expert group to test the European relevance of research themes, inspired by the recent 'Guidelines Communication'[6]. As is clear from the descriptions, the rationales are overlapping, but illustrate how research themes can be selected as candidate priorities for European research at quite different levels and with different patterns of justification.

[6] Ref Com. COM (2000) 612 final, op. Cit.

Research support

1. **Large-scale high-visibility projects.** This refers to areas of S&T research where there is a requirement for large-scale, shared-cost investments in installations and infrastructure such as transport or construction-technology demonstrators, test facilities, development platforms and other large scale facilities. Examples might include *next-generation nanoelectronics* with European-level development of a cost-*effective extreme ultra violet nano-lithography* facility.
2. **Building critical mass and exploiting economies of scale**. This refers to areas of research where the required scale can be achieved in a 'distributed' manner, rather than requiring a physical concentration of resources. In some areas, research efforts across Europe may be sub-critical due to redundancy and/ or a lack of co-ordination. Examples could include *bioinformatics* and *aeronautics*. The latter as an industry is highly integrated at European level while research is still largely carried out at national level.
3. **Development of mutual learning and knowledge sharing**. The pooling of complementary expertise and information exchange can help to remove redundancy and increase overall research efficiency - e.g. comparative research and exchange of personnel and expertise in *health-care delivery* and *tele-medicine*.
4. **Encouraging a long-term horizon**. European research should cover fundamental and emerging transdisciplinary sciences, which are the nursery grounds for tomorrow's technologies to underpin future competitiveness, wealth generation and improved quality of life. Such areas include basic *natural sciences* but also areas such as *nanoscience, complexity science, software science*.
5. **Tackling complex issues.** Several challenges facing the research community attain levels of complexity that make them de facto candidates for European-level activity. *Environmental sustainability* (e.g. climate change, pollution, ecosystem management) requires research into the highly complex interactions between business, all levels of governance, and individual consumers, and the phenomena arising from their actions.
6. **Bridging gaps in the innovation system**. Part of the European innovation paradox (whereby strong S&T capability is not translated into business advantages) is local, requiring concerted action to improve the links between the knowledge infrastructure and the productive components of the innovation system. Certain innovation systems have pan-European components (*automotive* and *agrofood* industries, *retail* and *services* - tourism, engineering consultancy, banking, e-business, logistics). European level research could help to alleviate systemic weaknesses in both respects.

Policy links

7. **Direct link to <u>new</u> & <u>existing</u> EU policy.** Where there are strong existing policies at European level, such as *agriculture* or *environment*, there is a case for European-level research to support policy development, or to use the policy frame as a stimulus for building European technology and innovation strengths. E.g. research in support of a viable and sustainable agriculture and rural environment in the face of structural changes related to enlargement, climate-change, GMOs, and rural depopulation; or research to provide the knowledge and reference information base for *nanotechnologies standards* issues and *IPR protection*.

8. **The issue addressed has an inherently transborder nature**. This criterion refers to research that supports a consistent European position on issues that are inherently international, such as the analysis of climate change (where common solutions may be needed. It also refers to a whole range of *standards, measurement and testing* and pre-normative research where common solutions to common challenges are needed (*waste and water management techniques, traceability of foodstuffs*).

9. **Support for the building of Europe.** This, including the preservation and deepening of European diversity, cultural heritage, traditions and identity, constitutes a strong justification for European-level research.

10. **Protecting individual citizens.** Individuals increasingly make transactions that transcend the jurisdiction of individual nation states. Food products, environmental pollution, transmissible diseases, global computer networks, international web-retail, personal security, crime, illicit and performance-enhancing drugs, privacy intrusions are just a sampling of issues where European research may be justified - e.g. to *understand, regulate and mitigate* the risks and threats which affect individual citizens.

11. **Developing public confidence.** Many recent issues such as genetically modified crops and foodstuffs, cybercrime, BSE, health and environment damage caused by industrial accidents and negligence, point towards a basic crisis of confidence in society as a whole vis-à-vis the science and technology system. As part of winning back public confidence, a much reinforced research effort will be needed of a risk assessment, monitoring and mitigation, precautionary and anticipative nature.

Performance and International position of Europe

12. **Building on strengths**. Europe has certain areas of clear strengths and research excellence that need to be supported and nurtured, especially in the fastest moving fields of S&T. Possible research areas which might illustrate this include organisation and management sciences, marketing and logistics, embedded hardware and software technologies, (mobile) communications.

13. **Developing future leadership in critical areas.** Trends towards the integration of previously separate technology areas means that today's portfolio of research capabilities is not necessarily a sufficient base for tomorrow's technological leadership requirements. An example would be to develop the full range of know-how and capability to benefit from the next waves of *micro/ nanoelectronics*, whether it be on the back of quantum solid-state computing or bioelectronics.

Chapter 2 - Mega-Challenges for European Research

Introduction

From the expert group workshops and the background analysis[7] produced the following list of five Mega Challenges for European Research.

I. A Knowledgeable Europe to Compete in the Digital Economy: *harnessing together the old and new economies, knowledge systems for production and services, and life-long learning.*

II. Sustainable Development: *precautionary research, ensuring sustainability and security in the face of increasingly complex issues such as global climate change, food safety and information security that require assessment, management and mitigation.*

III. Lifelong Health and a Healthy Society: *the challenges of living longer, better and at an affordable cost.*

IV. Mobility and Energy: *integrated and low emission approaches to transport, urban development and energy systems in an enlarged Europe*

V. Building Europe: *enlargement, European citizenship, public confidence and raising awareness of European issues*.

These Mega Challenges were chosen on the basis of their relationship to research themes and the European relevance criteria (as laid out above in Chapter One). Especially, the selection was guided by consideration of the following underlying aims:

1. Support for growth, competitiveness and job generation through a more dynamic investment and a better co-ordination and organisation of research efforts
2. Creating a shared area of values by bringing citizens and S&T closer together, putting research and its social implications into the centre of the political debate and creating a wider culture of research and innovation.

These translate into strong requirements for European research activities, on the one hand to stimulate innovation and growth, and on the other hand to serve the needs of Europeans, and to address Europe's most pressing societal challenges.

It is worth noting that such societal and citizen orientations of public research policy debate, feature strongly in many recent national Foresight programmes (see Table 2.1), and in the problem-solving approach of the present Community research 'key actions'.

The sections that follow give a short description of each of these Mega Challenges. The underlying trends and trend-breaks that make them interesting in themselves are given, as well as their relevance at a European level and to potential research themes. Reference is made to corroborating evidence from national Foresights. At this stage we only signal the research implications at a broad level as a more detailed description of

[7] For this project a substantial amount of background supporting analyses were produced based on the most prominent societal and science and technology challenges flagged in national Foresight programmes The full list of themes covered includes: Education, Growth & Innovation, Health Systems, IPRs, New Economy, Aerospace & Defence, Agriculture, Energy, Environment, ICTs, Life Sciences, Manufacturing, Nanotechnology, Organisation & Soft Technology, Transport & Mobility http://priorities.jrc.es/

specific research themes is developed in Chapter Three. However, for each theme an indicative chart is provided that points out the broad main correspondences between the Mega Challenge and the S&T areas discussed in the next chapter.

Table 2.1 Key societal topics in recent and on-going Foresight

Key theme	Main theme for Foresight
Sustainable environment	8
Built environment, urban life, housing and use of physical space	6
Knowledge, skills, lifelong learning, training	5
The future of manufacturing	5
Healthier living	5
Global competition and integration	4
Ageing of society	4
Mobility and communication	3
Changing patterns of working life	3
Ethics and privacy	2
Values, Culture and Social Cohesion	2
The Organisation of Society & Democracy	2
Crime	1
Enlargement	1
Sample: Fondazione Roselli, Italy (on-going), German Futur (on-going), Norway (on-going), Sweden 2000, United Kingdom, IPTS Futures Project 2000, Austria 1998, Japan Sixth Technology Delphi 1997 Portugal 2000, Australia 1997, Rand Critical Technologies, US 1998, New Zealand 1998, Ireland 1998	

Mega-Challenge I - A Knowledgeable Europe to Compete in the Digital Economy: *harnessing together the old and new economies, knowledge systems for production and services and life-long learning*.

The transition to a knowledge society was seen as important enough to merit specialised panels in at least four recent Foresight reports (IPTS, SW00, UK00, A98). It was also one of the strongest clusters identified in the expert workshops. Basically it addresses the growing importance of activities based on “intellectual” labour, and its application in both new and established sectors of the economy. This includes not only those based on codified scientific and technological knowledge, but also tacit knowledge and skills, works of art and creativity, ideas, views, beliefs, and preferences.

One of the few certainties about the move toward the knowledge society is that it is driven by the revolution in information processing, based itself on enabling information and communication technologies (ICTs). The importance of sustaining further development of ICTs is discussed in the S&T chapter. However, the challenge of building the European Knowledge society is not only to have the best available enabling ICT technologies, but also to know how to benefit from the opportunities a changing economy offers, to understand and make the best out of Knowledge as core structuring aspect of our societies, and to “empower” people and society by improving the overall knowledge levels through adequate knowledge generation and training institutions.

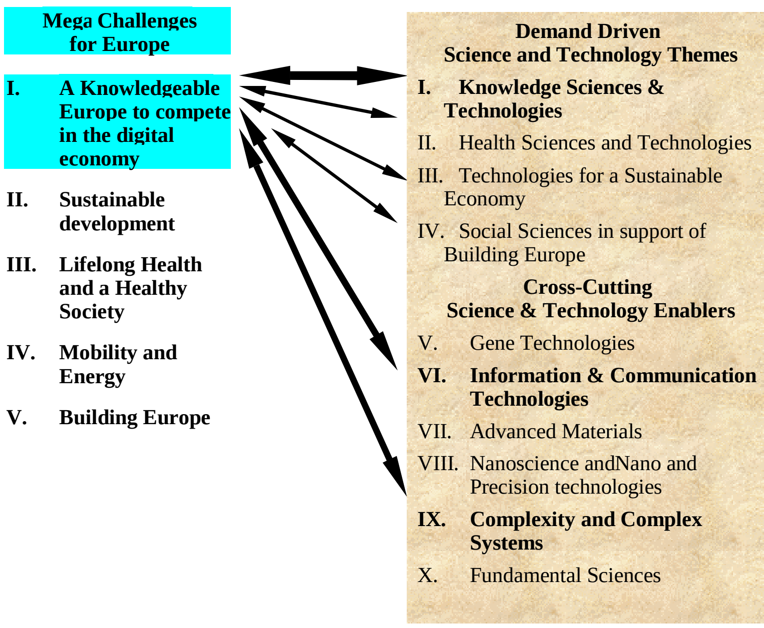
Competitive success in the knowledge society calls for prowess in both hard and soft sciences and technologies. In an increasingly networked and globalised business environment, most revenue and wealth accrues to those geographical centres where the business-enabling technological and intellectual capital resides, regardless of the location of operations.

For the purposes of analysis we have divided the wide array of pervasive changes stemming from this Mega Challenge into three strongly interconnected groups: the 'knowledge economy', improving knowledge generation and use, and the learning society.

The 'Knowledge Economy'

The challenge of the so-called new economy derives from the observation that knowledge - in the wide definition - becomes a major driver of economic growth and competitiveness. Whether this really leads to a 'new economy' in which new rules-of-the-game apply and in which new activities and entities define the face of the economy, is still under debate. As of now, the 'new economy' is being harnessed to the 'old' in three different ways:

- By providing the generic means to organise economic activities in completely different ways
- To substantially change the locus of economic value from material to intangible characteristics
- By providing opportunities for entirely new products and services to emerge together with new industrial and service sectors



This argument is so far largely rooted in the direct and indirect economic impacts of ICTs. But it is expected that in the future other widely applicable enabling technologies such as genetic engineering and nanotechnologies will compound these kinds of impact.

Improving knowledge generation and use

With the growing importance of knowledge and knowledge-based products and services in the economy and society, there is a major challenge to improve the generation and use of knowledge on a number of fronts:

Improving science and technology: apart from the obvious challenge to increase overall investments in science and technology, the systems and institutions concerned with research and technological development need to change as well. A strong science and technology system depends upon being able to attract the best brains into research.

In particular, it is necessary that the brightest and most gifted researchers are attracted to work in the European research system. Mobilty within the system and internationally is a prerequisite in order to encourage learning and knowledge exchange. In addition new fields, especially emerging transdisciplinary ones, need special encouragement.

Creativity and entrepreneurship: the use of knowledge will need special fostering on the one hand, by providing very good conditions for access, (property) rights and for creative work (this includes building the content for the knowledge society), and on the other, by cultivating a entrepreneurial culture.

Understanding the user: an essential challenge for the knowledge society is to improve the understanding of how communities and individuals think, communicate, track and build up knowledge, consume and evaluate information. This is not only a challenge to work on socially acceptable technological trajectories, but also to recognise and exploit the knowledge of users as a source of new developments.

The learning society[8]

The concept of knowledge extends beyond the codified scientific and technological skills of a select group to include the whole diverse set of tacit knowledge and skills (including interests, views and opinions) in society. Thinking along these lines, the concepts of knowledge economy and knowledge society refer much more to a growing importance of the overall knowledge and skills levels in society and not only to growing importance of science and technology as drivers for development. This leads to a qualitative change that raises a series of educational issues at the heart of the knowledge society project.

The knowledge society must thus be a learning society. The basic challenge is to build learning organisations and systems. With the availability of many very broadly applicable enabling technologies, the range of choices about what to make, what services to deliver and where we want organisations and societies to go, will grow. This has two major consequences. One is the need to find ways of managing innovative and creative processes in organisations, communities and in society as a whole. The second is that learning should become part of everyday life. This points to a major challenge for educational sciences and science-oriented prospective analysis to reshape our knowledge institutions and their practices. Beyond an overall increase of investments in science and education, the systems and institutions concerned with research and training need to change as well, while allowing new ones to emerge.

The European dimension

Building on strengths. Europe has recognised advantages which could be exploited much better on a European level. Some of these have to do with the quality of basic science and technology in certain areas, but many are also related to the capacity to apply and benefit from new technologies in specific sectors and types of application.

Developing strengths in critical areas. However, Europe currently lags behind in many of the key enabling technology areas needed to develop the new economy. This calls for a reinforced effort in core enabling ICT components, devices, systems and platforms, including software and the broader adoption and customisation of ICT goods and services at a sectoral level. It also calls for preparing the way for other emerging enabling technologies.

[8] See the IPTS Futures Project Report on Knowledge and Learning.

Bridging gaps in the innovation system. The pervasive use of ICTs in business activities changes profoundly our ways of production (automation, distance control, etc.) and trade (e-commerce), the relations between and within organisations and, last but not least, the business models they develop in renewed value networks/chains. The emergence of these new patterns of interdependence raises major questions concerning its understanding, its sustainability and its potentials from an economic, social, political or regulatory point of view. Even if not all of the economy will become networked and virtual, *understanding the dynamics of e-conomy*, the current transition path, and *modelling its dynamics while being supportive to our industries*, is an essential research objective. This will help to avoid excessive apocalyptic or utopian visions, and point to new forms of (corporate) governance. Many of these issues have to be dealt with on the level of a unifying Europe.

As a top-level consideration for European research, it is necessary to enhance the performance and attractiveness of the European research system. Especially important is the ability to sustain leading research institutions and a high-level skill base; to build on Europe's fine tradition of higher education and universities especially in science; the matching educational demands and supply through increased cross-disciplinarity to meet the needs of modern society, protecting against potential dominance of internationalised US education on-line lifelong learning institutions.

New and Existing EU Policy issues. Policy issues include the need to support the integration of common education & training systems especially for professionals (engineers, doctors, researchers) as an aid to mobility within Europe and the Single European Market. Also relevant to policy is the enhancement of regional and social cohesion - creating the know-how to mobilise high technology opportunities for society as a whole, avoiding gaps between winners and losers (cohesion) and enabling low qualified people.

Developing leadership in critical areas. There are opportunities for the emerging European knowledge management industry to build on European strengths in managing multicultural workforces, data-mining and warehousing. This would require reinforcement of the emerging European-based pedagogic tools industry: including production of electronic content; transnational, -cultural and -linguistic learning support; development of mass customised learning platforms people to permit modes of flexible learning institutions (distance learning, auto learning and lifelong learning).

Mega-Challenge II - Sustainable Development: *precautionary research, ensuring sustainability and security in the face of increasingly complex issues such as global climate change, food safety and information security that require assessment, management and mitigation*

Technologically advanced society provides solutions to many problems of risk and sustainability but nevertheless creates its own set of serious risks, in particular in the areas of environment (e.g. climate change, threats to bio-diversity), health (e.g. BSE, food safety) and social compatibility (e.g. threatened privacy by using genetic information or ICTs). Three main trends can be identified that aggravate the risks:

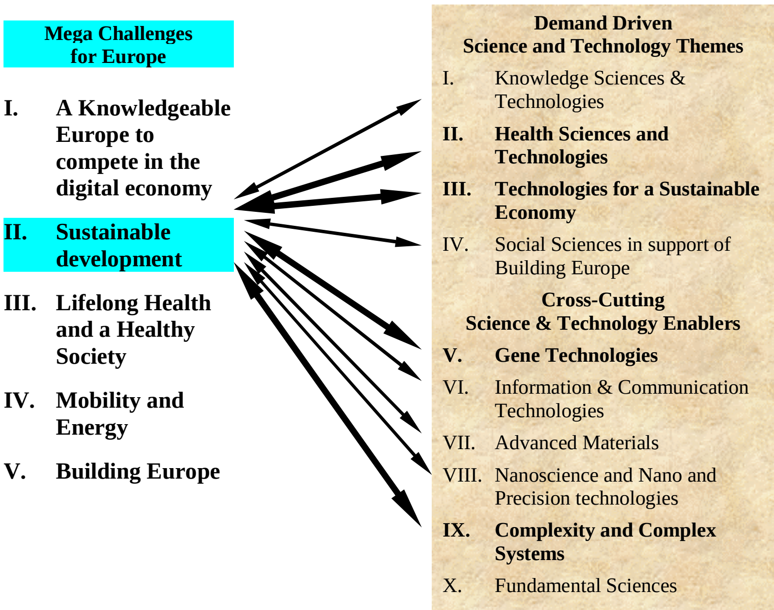
1. There is an increasing contrast between applied R&D leading to a faster turnover of new products and technologies on one hand, and delayed and fragmented scientific understanding of the medium- to long-term consequences of such innovation on the other (e.g. millions of hectares planted with various GMOs long before having understood problems and advantages).

2. At the same time, the increasing complexity of interactions between technology, society and the environment is gaining a new dimension, which makes it increasingly difficult to understand those consequences (e.g. relationships between climate change and agricultural production).
3. Also, the limits in the carrying capacity of various ecosystems are being reached (e.g. soil in many agricultural and forest areas), which creates new economic, social and health risks and the need to manage natural resource and the environment in a prudent way.

Such challenges call for different lines of research at a European level. First, it is necessary to understand the nature of the risks. Second, risk-management methods are needed to avoid or reduce the risks. Third mitigation technologies need to be developed where the negative consequences of human action are already being felt. Market failure to address such longer-term-problems will in many cases require public funding to ensure they are tackled in time and in sufficient measure.

The European dimension

Support for European policy. The European Union increasingly speaks with one voice in international negotiations and agreements related to global environmental risks such as climate change. The negotiating position relies to a large extent on leading edge European research informing about the nature of such risks. Strengthened international co-operation with global partners in such research is one factor to improve the European position (D98). Another is to develop further European large-scale efforts in areas such as remote sensing and modelling of complex systems. This position is weakened in that in some areas, such as basic research for under standing ecosystems (e.g. taxonomy and understanding biodiversity) where European research is currently quite fragmented.



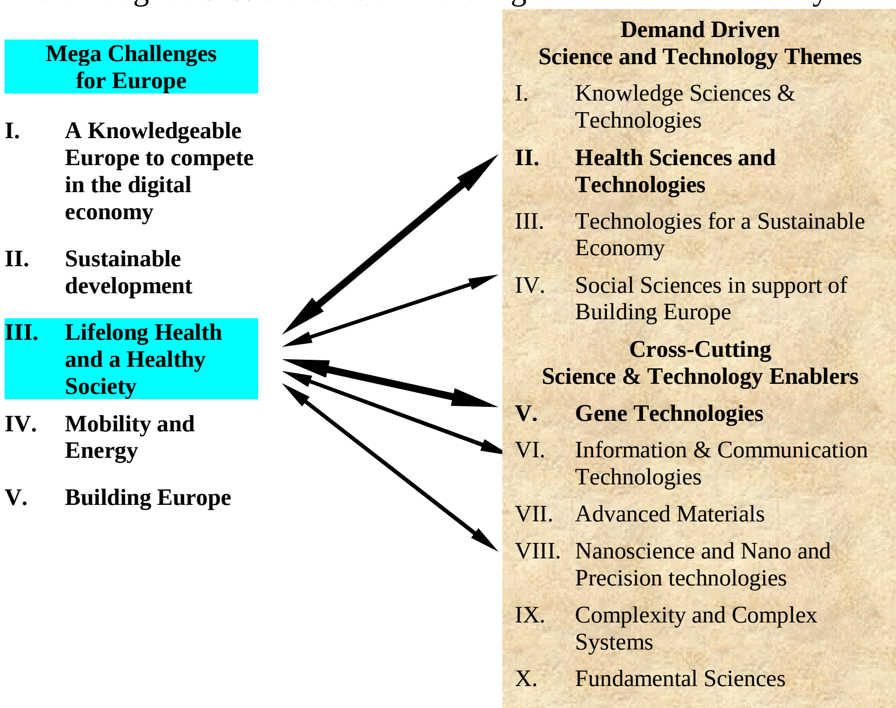
Public confidence. Recent crises (BSE, GMOs in food) have shown that the management of health risks and food-safety need to be improved in Europe (see also Mega Challenge III). An important factor is high quality and reliable scientific evidence to back up decisions. Related research would be more effective with measures to raise mutual trust across Europe.

Governance systems to manage risks are confronted with the challenge of applying the precautionary principle in case of scientific uncertainty while not missing key opportunities by being too defensive.[9] A strong European science base in precautionary research (e.g. relating to issues such as GMOs, endocrine disrupters) and effective mechanisms to link it with the governance system are crucial for protecting the health of citizens and the environment as well as for guaranteeing the competitiveness of European industry.

Protection of the Individual citizen. Research is needed to develop ways to mitigate such risks from the threat to citizens' privacy as new types of personal information (in particular genetic) become available, and the possibilities to store, process and transfer data throughout Europe and beyond, explode. In addition, policy making needs support from social research that helps to anticipate reactions of different societal groups to new risk management procedures and rules as part of increasing societal dialogue on scientific issues. Special attention needs to be paid to the European cultural diversity in dealing with risks.

Mega-Challenge III - Lifelong Health and a Healthy Society: *the challenges of living longer, better and at an affordable cost*

The cluster of issues that characterises this European Mega Challenge covers the health of Europeans, general quality of life questions, and the balance of the societal system. The main watchword is health. Europeans are living longer with high chances for a good quality of life throughout. We also claim the right to live in a healthy society away from physical threats, excessive stresses, and so on. But these expectations are offset by the fact that an older population tends to have higher health-care costs such that we face a rising societal bill in the area of healthcare provision. In the last three decades, EU health care spending has substantially increased in terms of GDP: from 5.3 % in 1970 to 7.2 % in 1980, 7.8 % in 1990 and 8.6 % in 1997. This percentage may still increase in the future: forecasts in several Member States point out that, in 2020, close to 40 percent of population will be older than 65 years.



The importance of this challenge (health, quality of life and ageing) is corroborated by its appearance as a main focus for six of the most recent Foresights (IPTS, SW00, I00, J97, D00, A98). This was reconfirmed by our expert group's identification of key emerging requirements relating to:

[9] Ref: Commission paper on Science and Society.

- a society that is growing older
- new health service challenges (new and re-emerging diseases) and opportunities (tissue-engineering and genomics)
- understanding the health implications of new agricultural techniques and environmental, technological or lifestyle risks (see also the Mega Challenge II on Sustainable Development)
- the need for a built environment that is comfortable, efficient and safe
- greater self-actualisation such as rising demands for leisure services and products

The research challenges range from design and management of more efficient health care systems to the adoption of new medical technologies, from the understanding of the social and economic opportunities offered by the post-sequencing genome age to the analysis of safer working and domestic environments.

The European dimension

Building critical mass and **exploiting economies of scale.** The research fields that are emerging in response to new challenges (post-genomic research, gerontechnology, new immunology programmes to tackle re-emerging diseases) can be built up quicker and more effectively by pooling the critical mass through co-operation on research design and clinical trials networking to share results.

Developing public confidence. Common standards or approaches on inherently cross-border issues also constitute a critical need. Examples include ethical concerns relating to new treatments or new health threats, health-related risk associated with the applications of science or in the use of technologies to track disease vectors across national borders.

Development of mutual learning and knowledge sharing. In looking for solutions to health systems redesign, it is impossible that there will be one solution for all. But working together on themes such as the shift from Reactive Repair to Proactive Care (i.e. prevention, health education, sport, nutrition issues), has potentially strong learning effects and scope for open co-ordination methods such as benchmarking of results from evidence based medicine.

Mega-Challenge IV - Mobility and Energy: *integrated and low emission approaches to transport, urban development and energy systems in an enlarged Europe*.

Mobility and Energy Systems are essential enablers of the social and economic development of society. In both areas, problem pressure has increased over recent years and given rise to concerns about their sustainability. Not surprisingly, both topics appear regularly on the priority lists of national foresight exercises (UK00, A98, J97). They are particularly difficult challenges in the context of sustainable urban development where the need is for a holistic management approach along with other interdependent challenges such as health, land-use, business development, etc.

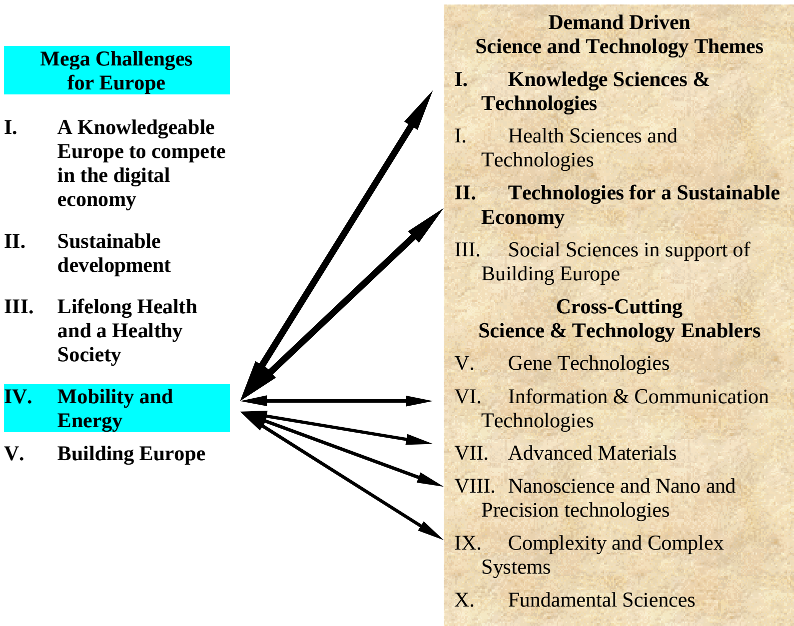
The modernisation and restructuring of energy and mobility infrastructures are also key issues for the pre-accession countries where there is a major backlog to be addressed over the next years.

Energy and mobility systems take a long time to evolve, either due to the long life-time of infrastructures, but – in the case of mobility – also due to the entrenchment of mobility behaviour in lifestyles and values.

Both sectors are dominated by a few technologies, notably the car and fossil fuel. A major aspect of the challenge is the diversification of the sectors to improve security of supply as well as environmental performance.

Energy Systems

The recent growth of oil price has shown once again how vulnerable and dependent Europe is on reliable petroleum supply from politically unstable world regions. Energy at an affordable price continues to be critical to Europe's economy. In the longer term, concerns about climate change and the resulting international agreements on the reduction of CO_2 emissions require Europe to come up with new, more sustainable solutions.



Several technological options are currently under development, but might only substitute for fossil fuel shortages in the long term. The main promising pathways – the hydrogen economy based on alternative nuclear fission techniques (perhaps thorium reactors) and decentralised energy supply based partly on a range of renewable resources - imply restructuring and partly reconfiguring the supply system as part of such a long-term transformation process.

Mobility

Transport is a major contributor to CO_2 emissions, and the one with the steepest increase in fossil fuel consumption. Technological improvements over the past years allowed the reduction of emissions (NOx, SOx, particles), but the reduction in fuel consumption per vehicle-kilometre has been more than outweighed by growth in transportation volume.

The volume of traffic is also at the origin of the second main problem in the transportation field: congestion, by which especially air traffic is heavily affected. Urban areas and road freight traffic are equally under pressure. Railway systems along major axes are reaching their capacity limits.

For both reasons, strategies to achieve the de-coupling of economic growth and transportation demand will need to be set in motion. A broad range of new emerging and old improving technologies are expected to contribute to such strategies.

There is also still much scope for service innovations in the mobility field in order to improve the efficiency of services, including the availability and costs of intermodal mobility chains, which – for the moment – are still underdeveloped.

The European dimension

Building on strengths. Europe has a tradition of design and implementation of large-scale, socio-technical systems for energy supply and mobility, through its tradition of urban and regional planning and participative policy implementation involving the range of social and economic actors. European firms that are accustomed to operating in these environments therefore are well placed to provide integrated solutions rather than stand-alone technologies. This is a major opportunity area also with respect to foreign markets, on which European firms could benefit from combining and reinforcing their strengths.

Building critical mass and exploiting economies of scale. Economies of scale have been a key characteristic of energy and transportation systems over decades. In fact, we currently see the emergence of a Europe-wide mobility industry, integrating suppliers as well as end-users. Such border-crossing networks require a research basis that overcomes national borders.

Transborder nature. High-performance cross-border infrastructures for energy and mobility are a vital element for the efficiency and competitiveness of Europe's economy. Integrated mobility systems are also a major direct benefit for European citizens.

Direct link to new and existing EU policy. Research on mobility and energy-related issues is also needed to support several EU policies, especially those dealing with CO_2-emissions and the environment, but also to underpin energy and transport market deregulation.

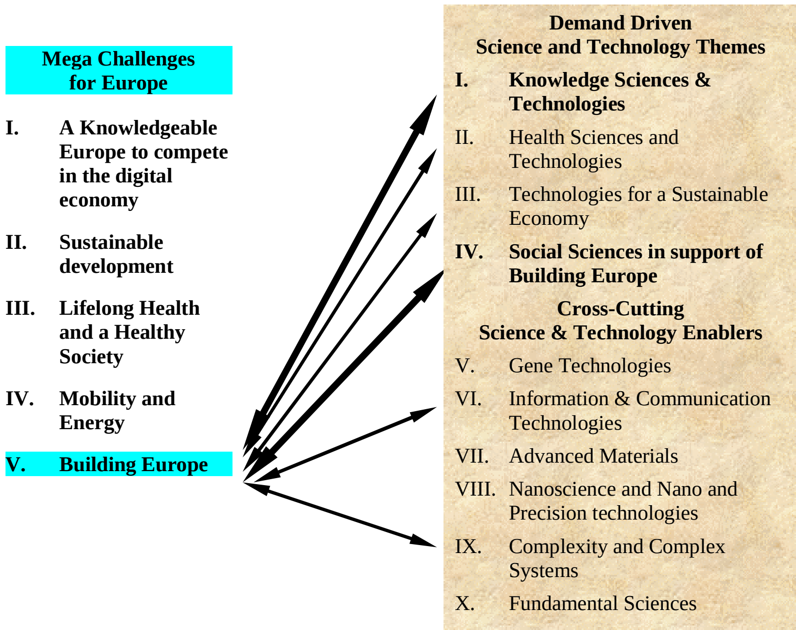
Mega-Challenge V – Building Europe: *enlargement, European citizenship, public confidence and raising awareness of European issues.*

For 50 years now, Europe's identity has been rooted in a diversity of people living together in a conflict-free space and sharing a number of common objectives: democratic political principles, social cohesion, consciousness about their environment, shared core values and ethical principles, multilevel governance and a fairly balanced role in international affairs. The challenge consists of continuing to take advantage of this richness under fast changing framework conditions, and to continue doing this in a democratic and conflict-free way.

Globalisation questions the ability to maintain cultural diversity, raising fears of losing identity in a society that is dominated by footloose economy and cultural homogenisation. Nurturing diversity in Europe, but based on some common grounds, is essential to prevent this from happening. Enlargement and possible migration flows from the Southern and Eastern[10] frontiers of the EU and further afield, will increase diversity in a quite fundamental way (habits, religions, ethics, women's role in society, alphabet, etc.) and, if managed correctly, can enrich, rather than compromise the core elements of the evolving common identity.

Values and lifestyles are changing continuously and question established political practices. New forms of governance and multi-level democracy have been recognised as key requirements to maintain trust in the common institutions of an enlarged Union.

At the new borders of the Union, currently being moved in the process of enlargement, the relationships with neighbours will need to be defined. There is still potential for violent conflicts in the neighbourhood of the EU, as tensions in the Balkans may demonstrate. Europe may have a tradition of careful and balanced intervention in such conflicts, but it still depends on US support for most kinds of military interventions.



The falling of borders also opens up inroads for organised crime, operating across and within the borders of Europe in the form or "macro-crime" and given the global nature of the Internet "cyber-crime". While if social cohesion falls within the Union marginalisation and social conflict could increase, leading to a social strata of underprivileged and possibly rising rates of "micro-crime".

However, one should not let the potential threats overshadow the extant advantages that can accrue to Europe in managing migration pressures, encompassing new cultures, and propagating European ideals and influence within and beyond its borders. This has implications for improving two-way trade, internal competitiveness and cohesion, and in creating a healthy counterpart to the US on many global issues, around which alternative positions can rally as appropriate.

The European dimension

European identity is almost by definition a subject to be addressed by European-level research. Apart from its explicit consideration in the European Treaties (e.g. regarding social policy, justice and internal affairs, common foreign and security policy, etc.), there are several substantive arguments to be taken into account.

[10] The hypothesis of an important east-west migration flow across Europe in the next few years was strongly counter argued by the expert panel of the Futures IPTS Project.

EU-policy issue and **Developing public confidence**. It is necessary to develop a truly European wide base of scientific and technological reference, covering measuring and testing for trade, industrial norms and standards, food safety, monitoring of compliance with legislation, and so on.

Building Europe. Scientific and technological research to support the advancement of European identity is based on a common interest in its outcome. Two examples are language technologies and encryption.

Protecting individual citizens and **Large-scale High-visibility projects.** Research in relation to security and safety is rooted in the common interest of protecting Europe's citizens. This may require large-scale efforts, such as in the case of space-based monitoring.

Direct link to existing EU policy. Research work is also needed in order to support EU policies, especially in those fields where the EU has acquired new competencies over the last years, such as e.g. in external relations.

Building 'European awareness'. Finally, the building of elements of European awareness and culture, while complemented by regional specificity, would help create a stable nucleus of European identity.

Chapter 3 - Science and Technology Areas

Introduction

This chapter identifies a series of science and technology areas of high importance and potential opportunity for Europe. The selection was governed by the European-relevance criteria and basic principles set out in Chapter One. One of the latter was the extent to which important emerging or potential trend breaks in science and technology could be flagged. Such S&T areas present themselves as new opportunities and fields of development from which Europe cannot afford to be left out. Trend breaks tend to be in quite new areas (such as biogenomics) or the growing transdisciplinary fields (such as nanotechnologies). These areas offer high opportunities for Europe to forge ahead more confidently by developing economies of scale and scope, working together to build critical mass. But trend breaks can also take the form of fundamental paradigm shifts (new knowledge & services dominated manufacturing, move from reactive to preventative health care) or reformulation of older problems (risk & precaution research in response to radical changes in citizens perception of S&T).

Big opportunities are also apparent in application areas where Europe has a leadership position to sustain (mobile communications or embedded systems) or to build (knowledge systems). In these cases, the S&T areas are strongly related to the creation of the range of complementary competencies needed to maintain and develop technology- and science-based industries. For example, Information and Communication Technologies (ubiquitous computing & communications) and Environmental Technologies both call on a range of skills across different areas. Some of the S&T areas here are also fundamental enablers of the technology system (e.g. complexity, materials, nanotechnologies, information systems).

The list below groups the main areas of science and technology that result from the prioritisation exercise with the expert group.

Science and Technology Areas

- Demand-driven Science and Technology Themes

  I. Knowledge Science and Technologies
  II. Health Sciences and Technologies
  III. Technologies for a Sustainable Economy
  IV. Social Sciences in Support of Building Europe

- Cross-cutting Science and Technology Enablers

  V. Gene Technologies
  VI. Information and Communication Technologies
  VII. Advanced Materials
  VIII. Nanoscience, Nano & Precision Technologies
  IX. Complexity & Complex Systems
  X. Fundamental Sciences

The *demand driven* list directly relates to the Five European Mega-Challenges outlined in Chapter Two. The *cross-cutting enablers* are also be linked to the Mega-challenges – as was indicated in the side figures in the previous chapter. But they are pulled out here because they have a special significance as generic underpinning technologies for both the Mega Challenges and other areas of S&T research. These are the broad enablers of technological advance. There are, as a result, some overlaps between these sections. This is inevitable given the importance and cross-cutting nature of many of these fields of research.

The final item on the list, Fundamental Sciences is particularly important. European Research surely will involve support for high risk and/or long term fundamental science[11]. It is accepted that ‘big science’ sometimes requires scales of investment in facilities that cannot be achieved by countries acting alone (particle accelerators, synchrotrons, radio telescopes, shared Internet infrastructures for e-Science). But also important will be continued effort to raise the effectiveness of networking in emergent areas of research to create viable levels of research interaction and support for nascent or widely dispersed research communities (e.g. in quantum computing, or brain research). Notwithstanding it importance, this theme is not further developed here as it is one area which is so rich, diverse and inherently uncertain that it may be prudent to leave it as an open and flexible for the new ideas and creativity that emerge from the scientific community itself.

Each of the nine other S&T areas are described in the following sections. Some more detailed examples of technical research issues are presented, drawing on the supporting material produced for this project as well as the proposals made at the expert workshops. In doing this, the intention is not to be comprehensive but to illustrate at a finer level of specification the sort of topics which came up, and from which European-level research activities might be built.

Part 1: Demand-driven Science & Technology Themes

S&T Area I: Knowledge Sciences and Technologies

Definition (key trends/opportunities). Knowledge sciences and technologies, refer to the instruments, routines and required know-how for all organisations to function effectively and competitively - the harnessing together of the old and new economies - and for full participation of citizens. In the future, knowledge, viewed as a capacity to deal with complex and multidimensional information in a timely fashion, will become an ever stronger determinant for the success, growth and competitiveness of any economic and social system. It will be reflected in the capacity to develop efficient forms of organisation and knowledge management (creation, storage and retrieval). Education and cultural technologies will have a critical role, enabling individuals and enterprises to cope with increasing levels of complexity.

ICTs play an important underpinning and pervasive role in knowledge sciences and technologies impacting basically on three “levels” (see S&T Theme VI):

- as generic tools for communicating and processing information,
- as “vectors” for building new products, services and processes in many different sectors of society
- as the originator of new content and content based services.

[11] Fundamental 'big' science is a forerunner of European-level Research: CERN for particle physics, the European Molecular Biology Laboratory, or research instruments such as the Institut Laue Langevin research reactor and the European Synchrotron Radiation Facility, both in Grenoble, France.

Knowledge sciences and technologies, therefore involve a strong ICT dependence, but also include many other softer areas of S&T which are more tacit and contextual or human-factor dependent. These latter are equally important components of any individual's, group's or organisation's knowledge capital.

Overall drivers affecting this area of technology include:

- An urgent need for effective mechanisms and regulations to assure quality and protection of knowledge and IPRs in order to underpin value creation.
- Rising requirements for effective and widely useable soft (organisational and societal) technology. Scientific research as well as technological development projects need to be evaluated according to their organisational and social context and complemented by their social and organisational implications.
- The requirement to describe and understand mechanisms of knowledge formation, transfer and exploitation. E.g.: the extension of data mining, data warehouse into user friendly 'thinking tools' based on dynamic and distributed databases.
- Tools for new forms of business organisation, especially for SMEs, where networking will have a high value-creating role, e.g. how to improve co-operation mechanisms between organisations, how to facilitate cultural learning and adaptation in the case of mergers and acquisitions, how to understand the best organisational structures and processes to facilitate work in an intercultural environment.

Knowledge Sciences & Technologies
Strategic Foresight Statements

- Europe is weak in creativity enhancing tools (F00)
- Intelligence systems will have widespread use in companies by 2005 (UK95) and in society by 2020 (D97)
- Tele-teaching is established by 2010 (A98)
- New forms of value creation and organisation by 2008 (F00, D97)
- Widespread networking between companies by 2008 (D97)

Key research fields:

At a basic level, major research needs to be sustained and extended to improve European ICT competence and its industrial base. At present the centre of gravity is in the US as far as a large part of the generic tools (except some communications sectors) and the content are concerned.

The following areas of research are needed at the level of businesses and firms and by the research communities that support the productive sector:

Knowledge Management & Learning Organisations. The fundamental driver is the search by organisations to capitalise more productively both codified information (in databases, documents) and tacit knowledge (in everyday routines, in minds of people). Many of the new techniques are shifts in organisational behaviour that try to adjust business processes, incentives or organisational structures in order to get high output from the same input factors. Recent popular techniques include business process re-engineering, learning by doing, total quality management, high performance work groups, training, de-layering, employee empowerment and many other overlapping.

Also with the rising importance of information and knowledge as commercial assets in their own right, the management of intellectual property rights is a crucial area of business development. Techniques are patent databases, copyright control and monitoring of breaches. Also important are systems for registering and exploiting the vast reservoir of currently untapped information emerging from currently non-automated systems such as lab books and even automated areas such as transaction processing or fault monitoring systems.

Soft Technologies. Soft technologies refer mainly to the underpinning technologies that support knowledge management. Mostly these fall into the traditional categories of information capture, storage retrieval and processing. Today's techniques emphasise user friendly data storage and retrieval techniques, individual decision support tools and techniques to aid creativity of groups (such as electronic meeting systems, scenario developments, interactive video walls). In addition there are dedicated systems for electronic resource analysis and planning (manufacturing, personnel, goods), client tracking and account management technologies, simulation tools and supply chain management for industry and services.

Many of these soft technologies are now so familiar that they are almost invisible (document processing, spreadsheets, presentational tools) these will be now supplemented by e-publishing tools. One important development along these lines might be signalled by Microsoft's 'NET' strategy which builds on the fact that web technology has created a world-wide constellation of computers, devices and services. Their new thrust aims to provide a nested set of tools to permit these distinct parts to work together in a seamless manner.[12] The idea being to create a unified knowledge tool environment spanning development, service delivery, content creation, authoring, browsing and o on.

New horizons are also found in the use of sensor systems for information capture, filtering and delivery, tagging, tracking and tracing technologies, distributed database management systems especially dynamic ones, data mining and warehousing. Also important at all stages of information movement will be artificial intelligence techniques (AI) such as middleware and agents that permit a step change in the possibilities of exploiting data. For example applications of AI would be able to undertake automated searches across distributed databases to look for potentially interesting regularities or anomalies. This development could include processing of information abstracted from ad-hoc linking of component databases to create new knowledge. Agents could also help people performance, for instance meeting management agents could have a context sensitivity capacity that would customise the informational environment in a meeting to aid identification of issues, focus and speed of working.

Also included are formal techniques for forward planning such as interactive models, formal human resource requirements planning, scenario building tools, technology and business trends scanning procedures. Finally, with firms increasingly operating in networks, correct procedures for sharing knowledge with other parties are important – this has implications for legal instruments in addition to techniques that enhance the productivity of knowledge.

Education & Learning Technologies. The learning process will spill over and spread out from 'specialised' places (schools, enterprises,..) to all places and contexts. ICTs will facilitate access to knowledge anywhere, anytime, but nobody knows what

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[12] http://www.microsoft.com/business/vision/netwhitepaper.asp

knowledge we need to learn. The efficiency of present learning processes/ systems is a major obstacle, and promising new organisational forms are not forthcoming. With this in mind, research is needed on the sociology of organisations, social construction of knowledge, learning mechanisms in organisations and among organisations (learning in networks, education at large) from a variety of perspectives (economics, business, sociology, psychology) and understanding of the learning process (neuronal biosensors).

The growing gap between the capacity of traditional teaching methods to meet in a cost-effective way the fast rising demand for training and retraining especially has emerged as a fundamental driver of 'e-learning' technologies. The cluster of technologies at stake includes easy to use content creation and delivery tools, web collaboration systems, automated tracking of individual and group learner programmes, systems for evaluation of learning outcomes for individuals and funding organisations, and e-commerce systems. These separate applications are increasingly being packaged come together to form 'e-learning platforms'. The usefulness of these applications will depend heavily upon crucial breakthroughs in ICTs, in particular wide access to low cost bandwidth for multimedia services (mobile and fixed access), datamining and warehousing, intelligent agents and middleware, speech recognition and visualisation techniques).

Research is also important on potentially disruptive technologies such as virtual teachers & mentors and greater understanding of the fundamental processes of human learning by individuals and groups (drawing on psychology, cognitive science, neurology). E-learning techniques should play a role here by providing new tools for structuring and tracking and therefore codifying different learning contexts (learning in face to face groups, off-line asynchronous or independent study).

Media Content & Cultural Technologies. The media industries are amongst the fastest growing and most dynamic industrial sectors. Europe also has some large players in the industry, even though the very largest corporate actors are mainly North American. In the media industries a key trend driving technological developments is the growth of the web. Indeed, content is increasingly becoming not only multimedia but also having to be distributed over multiple channels. Web based design and authoring tools for example are designed bearing in mind the need to use the same basic content on the mobile web, on audiovisual systems, Intranets, printed and television.

Given Europe's cultural and linguistic diversity it is clear that leadership in media and cultural technologies is a condition for the preservation of European identities and diversity. Also, enlargement brings a significant rise in the number of languages in use in the Union, thus placing extra emphasis on improvements in assisted if not fully automated translation devices and speech recognition technologies. This is an area that has already shown considerable advances in the past few years. The main challenges seem to rely in improving algorithms, lowing the processing capacity needed translate speech, developing systems that are able to work with less instruction, or operating in noisy environments, moving towards portable and lower cost systems that can translate in real-time.

Other knowledge technologies that are in the area of culture or heritage conservation are likely to rely on information science techniques, the mass cataloguing of paper based texts and other artefacts (tagging) and the creation of virtual libraries, museums, or other experiences. One particular application of knowledge technologies concerns a dual threat that the present will become an ‘information dark age.’ Acid paper based records of cultural and historical importance will degrade after about 100 years. The long term accessibility of computer-based media is in doubt due to rapid cycles of technological change affecting storage media (e.g. punched cards, tapes, magnetic hard and floppy, disks, optical disks) together with their read/ write technologies and rapid obsolescence of software.

Defence & Security Technologies. Intelligence and surveillance systems are likely very important both as part of building up trust and confidence and as a protection against cyber-crime and more conventional forms of illegal and anti-social behaviour. The base technologies here relate to detection such as space-based monitoring and observation; real-time surveillance of data traffic using datamining techniques, tagging and tracking technologies and identification techniques such as digital signatures or biometrics.

In addition data protection is a crucial issue especially given that use of Internet by business, administrations and private individuals is not at all secure. Neither is the next generation of the Internet likely to resolve this issue. Encryption and decryption technologies are fundamental, together with their own enabling techniques such as mathematical cryptography and very high power computing. Cryptography is likely to be a key driver of demands of massively parallel technologies and will possibly enhance demand for radical new processing techniques based on bio/DNA-chips and quantum computing. On the other hand a lot information security can also built up using intelligent agent techniques which employ rules to monitor and safeguard the level of exposure of relating to the size and sensitivity of the transaction, the status of the interlocutor and so on.

Why is Knowledge Sciences and Technologies a potential topic for European research?

Europe’s international competitive position depends upon a wide and world class uptake of knowledge technologies and tools. There are areas in which it is possible to build on existing strengths in the supply of knowledge tools (e.g. datamining and data warehousing systems, mobile web and content design). But Europe is not in a consistent position across the whole range of techniques needed to sustain these strengths and to move to the next generation of more integrated approaches. Generally Europe sits behind in the commercialisation of key enablers such as intelligent agents, language technologies and e-learning platforms. Such weaknesses could threaten the whole position. Because most of these knowledge technologies are effectively co-produced, the relatively low take-up of knowledge management techniques amongst EU organisations provides an inherent barrier to innovation leadership. Here there seem to be particular requirements to build a critical mass through networked experiments and sharing of knowledge.

The **policy agenda for the knowledge economy** particularly in respect of the relatively fragmented position of Europe on Intellectual Property Rights copyrighting of intangibles such as software, patenting of life and so on. As these intellectual assets are likely to be crucial wealth-generating aspects of the global knowledge economy research in support of the EU policy position is an obvious requirement.

There are very strong aspects of knowledge technologies that are in support of issues such as **building public confidence** and **protecting the individual**. This is obvious in potential applications of encryption and trust technologies. There is also a strong aspect of **building European awareness** particularly through applications of knowledge technologies to culture, conservation or heritage.

I. Knowledge Sciences and Technologies	Key: Main correspondences to Mega Challenges Knowledge (cyan) S. Development (yellow) Health (red) Mobility (green) Europe (blue)
1. (cyan, yellow, red, green, blue)	**Knowledge Management & Learning Organisations** generic – Techniques related to business processes, organisational structures, training, etc. changing organisational boundaries - networks & distributed enterprises, B2B, B2C; Security, trust & confidence, and personalization; Technologically enhanced production, distribution and consumption. Methods of production and delivery. Techno-intelligent organisations. Models for learning. Business ecosystems.
2. (cyan, yellow, red, green, blue)	**Soft Technologies** specific - Systems engineering, Distributed database management, Knowledge filtering and delivery; Datamining/ warehousing; Content creation and storage tools, Agent technologies, Sensors/ actuators, Integrated devices (eg product & service tagging) (Tacit) Knowledge creation, storage, retrieval and loss. Critical interfacing and consumption patterns. Customisation methods. Needs analysis. Marketing. Simulation
3. (cyan)	**Education & Learning Technologies** e-learning platforms (mobile and fixed access to info. and guidance) virtual teachers & mentors customised to specific learner needs; laboratory use (collaborative working groups); learning appliances (voice/ text/.., & behaviour recognition); understanding of the learning process (neuronal biosensors); organisational aspects (education at large); knowledge codification
4. (blue)	**Media Content & Cultural Technologies** Language technologies; Media content development and human-machine interfaces; Tangible & intangible heritage technologies, both ICT-based and traditional
5. (blue)	**Defence & Security Technologies** Space-based monitoring and observation; Encryption, data-mining and security management systems; Demining technology; Trust technology

S&T Area II: Health Sciences and Technologies

Definition (key trends/opportunities). The changing health demands of citizens are driven by rising standards of living and life expectancies, the ageing of the population and the high expectations generated by highly publicised developments in biology and genetics (the research implications of which are covered below under gene technologies). Apart from genetics, major breakthroughs are expected in other areas such as tissue and organ engineering, surgery and the treatment of disease. In terms of health systems, rising costs and the logic of healthier lifestyles are leading to a switch in emphasis from reactive care to preventative care in health-related policies, extending the boundary to the fields of nutrition and education. New organisational principles and management tools will need to be developed to help maintain health systems working efficiently.

Much can be gained from the efficient application of informatics and telematics in clinics, which is still in its infancy. Changes in working conditions, lifestyles and food production systems will lead to the emergence of new diseases, and re-emergence of old ones in more virulent form (e.g. legionella, food poisoning). There will also be the re-emergence of old diseases (e.g. tuberculosis, diphtheria and cholera) as a consequence of the increased mobility of people or antibiotic resistance.

Key research fields:

> **Health Sciences & Technologies Strategic Foresight Statements**
> - Surgery assisted by computer will be less invasive and reduce risks by simulations (high support due to three-dimension imaging) (F00).
> - Diffusion of home-based nursing care technologies and the development of injury and disease prevention and self-management techniques (J97).
> - Practical use of robots providing medical care support in homes, hospitals, specialised centres, etc. (J97).
> - Entirely artificial kidney by 2013 (J97)
> - Breakthroughs in nutrition science create large markets for nutraceuticals (UK95)

- Technology for elderly people: The autonomy and independence of the elderly will be supported by the development of alternative forms of assistive technologies & home-based nursing care technology, ranging from new forms of home and community care services (home help, day care centers, etc.) to a better housing environment for the elderly. The adoption of sensors, IT and remote care technologies (tele-care and tele-medicine) will be crucial in increasing functional independence among older people in their homes and provide them friendly diagnostic devices for telemonitoring of chronic illnesses.
- Preventative Health Care & Nutrition: The paradigm shift to a heavier concentration on preventive medicine will reduce the frequency of misdiagnosis and the societal costs for mistreatments. Individual risk assessment for some diseases based on genetic screening and lifestyle measures and ultra-rapid analysis using high throughput screening will be important areas of research. Health education instruments and techniques will increase the cost-effectiveness of preventive care and improve reactions to changing lifestyles and nutrition habits.
- Health-care Systems & Management Tools: Socio-demographic and technological changes will ask for new organisation and management structure of EU health-care systems. The analysis and comparison of different EU experiences as well as the establishment of a EU-wide system of information will be necessary for identifying best practices in services delivery. The enlarged EU will need better instruments for disease & epidemic control, risk assessment and management, and harmonisation in technical standards of health care equipment. Special attention should be devoted to the development of appropriate IPR regulation for pharmaceutical products.
- e-Health: ICTs will allow remote delivery of health care and support services and information to people in their own homes and the remote exchange and delivery of medical diagnosis, consultation and information (doctor-to-doctor and doctor-to-patient). Telecoms will permit remote monitoring of patient's condition or behaviour from a centralised facility. Telecare and telemedicine will be crucial for providing healthcare services to rural areas at a reduced cost, with consequent positive effect on social cohesion. Integration of ICTs, medical imaging and robotics will include image processing, virtual reality, storage analysis and interpretation, robot-assisted surgery, image-guided surgery and conform radiotherapy. The development of medical decision support systems will be an essential complement to evidence-based medicine, providing information, analysis or options to assist in diagnostic, therapeutic and prescription decisions.
- Tissue Engineering: Advances in cellular biology research, in particular in embryonic and adult stem-cells, promise a huge potential of providing a treatment

for several diseases where not properly working cells and tissues have to be replaced in the body (diabetes, Alzheimer disease, Parkinson's disease etc). It may be even possible to replace whole organs, thus solving the problem of shortage of donated organs. In connection with the therapeutic cloning or using the patients' own stem cells the problem of rejection of foreign tissue might be overcome. Progress in xeno-transplantation research and the development of artificial organs will contribute to move in the same direction.

- Biomedical Research: New prosthetics techniques and the use of new biomaterials will dramatically improve life conditions of people with handicaps. The treatment of new and re-emerging diseases as well as the treatment of non-communicable diseases is a whole set of research issues that should be dealt with in the next decade.

II. Health Sciences and Technologies	Key: Main correspondences to Mega Challenges Knowledge S. Development Health Mobility Europe
1.	**Gerontology - Gerontechnology** Ageing population - Assistive technologies & home-based nursing care technology; Patient friendly diagnostic devices for tele-monitoring of chronic illnesses prosthetics techniques
2.	**Preventative Health Care & Nutrition** Changing lifestyles and food production systems, health education instruments and techniques; functional and therapeutic food; Organic farming; rational drug use & over-medication avoidance;
3.	**Health-care Systems & Management Tools** experimenting, demonstrating and benchmarking new practices and organisations in health services delivery corresponding to a prevention paradigm; standardisation in R&D of health care equipment; Organisational development - transnational Tele-medicine, Risk management, risk benefits. IPRs for pharmaceutical products; Information systems for health and health knowledge management EU-wide; Improved early warning systems for disease & epidemic control
4.	**e-Health** ICTs for health care Bio-sensors and bio-electronics; Telemedicine and telediagnostic; Health data-storage and data-retrieval; health privacy and security; Imaging and computer assisted surgery; Medical decision support system.
5.	**Tissue Engineering** Cellular biology stem-cells; pre-natal care & 'repair' 'spare parts' -, reuse, tissue engineering artificial organs; xeno-transplantation;
6.	**Biomedical Research**: biomaterials; treatments for new and re-emerging diseases & for non-communicable diseases;
7.	**Health Risks Research** Medicine & the food chain risk and precaution-related research - (BSE, GMOs, new treatments/ drugs/ therapies/, environmental causes)
8.	**Research on Risks to Privacy & Personal Integrity** medical information risk and precaution-related research - (genetic information, hereditary diseases, medical records, cloning, insurance, ethical concerns)

Why is Health Sciences and Technologies a potential topic for European research?

Development of mutual learning and knowledge sharing. The increasing cost and complexity of health-care delivery can benefit from European-wide research to identify new and efficient organisational practices. Comparative research and data exchange among Member States will contribute to benchmark best practices.

Building critical mass and exploiting economies of scale. EU-wide collaboration in research fields, such as tissue engineering, will also help in building the required critical mass, achieving economies of scale and avoiding duplication of efforts.

Developing public confidence. Issues like food safety (BSE, GMOs) and the re-emergence of old diseases are often closely related to the mobility of goods and people in the EU market and consequently their inclusion among European research priorities has an evident rationale. These issues also call for an EU approach in order to improve public confidence, undertaking precautionary research in order to provide instruments for assessing and controlling the risk.

Direct link to EU policy. The health sector requires also the harmonisation of standards at EU level: medical equipment, genetic tests, pharmaceuticals and bio-products are just few examples that require a concerted action on regulation. In most of these cases, regulation will lead to the development of new approaches for the protection of IPRs, and provide a competitiveness boost to European industry.

Support for the building of Europe. Areas with insufficient access to hospitals and well-equipped medical centers, mainly rural regions, can benefit from research on ways of exploiting and further developing tele-care systems for diagnostic and surgery-type applications in connection with other more advanced EU health centers

S&T Area III: Technologies for a Sustainable Economy

Definition (key trends/opportunities). Many sustainability and environmental issues require direct R&D action. Sustainable economy issues relating to production, distribution and consumption concerns also have many research implications particularly for enabling and cross-cutting technologies (materials, ICTs and complexity).

Three main lines stand out:

- <u>Sustainable production and consumption</u>, which refers to the need to develop new socio-technical systems within which innovation, growth and the satisfaction of material and immaterial needs go hand in hand with environmental sustainability - i.e. de-coupling wealth creation from environmental impact. This will require radically new thinking and cultural behaviour, towards which first progress can be made via eco-efficiency, emissions control, enhanced recycling, etc.. Lead candidates for such new socio-technical systems may include transport infrastructures and logistical systems, and urban design, but should also eventually encompass all areas of the economy.
- <u>Management of natural resources and the environment</u> in view of the impact of human development on natural systems. Management here refers to local (e.g. aquatic systems at catchment scale) as well as global systems such as the carbon cycle.
- <u>Managing risks</u> and mitigating adverse effects of technological progress. This requires a reduction of <u>pollution</u> together with a better understanding of its effects and higher safety levels for citizens and workers.

Key Research fields:

> **Technologies for a Sustainable Economy**
> **Strategic Foresight Statements**
>
> **Sustainable Production & Consumption**
> - Circular business systems with closed flows and sale of functions are expected by 2025 (SW00)
> - Europe especially Germany leads globally on life-cycle analysis (F00) & design, production, collection and recycling systems (J97, D98, F00)
> - Europe is strong on plastics waste collection but only average on its recycling (F00)
>
> **Energy efficiency**
> - Wide application of low energy technologies for buildings is expected in Germany and Japan for the period 2010 to 2020 (J97, D98)
>
> **Monitoring**
> - Remote sensing for prediction of floods global monitoring of the stratosphere and maritime pollution and currents (D98).
> - The USA leads in global scale environmental surveillance (J97)
>
> **Management**
> - The USA leads in most environmental preservation technologies; but the EU leads in conservation of local ecosystems and creation of wildlife habitats (J97)
> - Europe's position in soil remediation/decontamination technologies is rated average (F00).

Sustainable production and consumption, has major implications for the design and development of business models and whole value-chan systems, as well as the design of products and processes at a more de-aggregated level. It requires the elimination of waste production from value generation through closed product cycles (re-use, recycling) which involves emerging areas as separation technology (an important element of many recycling technologies) and overhaul and repair technology, which is another option of 'revalorisation' (as a complement to recycling - cited in (US98). More incremental developments are still required in the reduction, recycling and treatment of waste, and minimisation of pollution from contaminated sites and sediments, as well as diffuse pollution from land use practices.

De-linking growth from energy use and control of atmospheric ozone and particulate matter emissions, requires major transportation and energy innovations. These include: alternative or more efficient energy sources (e.g. proton exchange membrane fuel cells for transportation applications and solid oxide fuel cell with co-generation for stationery applications, bio-fuels); new vehicle technologies (propulsion systems lighter vehicles, tiltrotors, all-electric ships); new organisation of the supply of transport and energy services (passenger and freight information systems, route guidance, road tolling, car share systems, traffic management, remote control of electricity flows, localised and decentralised approaches of combined heating, cooling and power ('trigeneration'); deeper infrastructural changes (integrated local/regional planning, incentives for transport substitutions, multi-modal co-ordination, transhipment centres, nuclear-hydrogen energy systems or a renewable-hydrogen system, energy storage/distribution schemes to offset the intermittent character of renewables, safety techniques to handle it).

The management of natural resources calls upon the following fields: monitoring/observation/surveillance of natural systems: at various spatial scales using remote sensing, sensor systems; analyse/ understand/ model natural systems and their interaction with socio-economic systems requires interdisciplinary and participative research integrating scientific, technological and socio-economic aspects; technologies for sustainable exploitation of natural resources; technologies to mitigate or restore damages; the development of operational management schemes.

Managing and mitigating risks from environmental factors involves: techniques to control congestion and raise safety are based on more integration of individual vehicles into a system through information sharing or enhancement of complementary use of a shared traffic system: co-design of active and passive safety, automated guided vehicles, anti-collision systems, information systems to manage traffic (air, ship, rail, road), tracking and tracing; assessment and reduction of health effects from environmental factors, and support to health and environmental policy-making and public information.

A general challenge for the longer-term will be understand and analyse the cross-impacts between environmental systems that operate at very different temporal and spatial scales, both natural (e.g. the carbon, water, nitrogen, phosphorous, sulphur cycles as well as the biosphere). This clearly requires developments in complex systems research (see S&T Challenge IX), espcially considering that such models should also take account of socio-economic effects on the environmental systems. Underpinning such analyses will have to be transdisciplinary research into more sustainable modes of production, distribution and consumption, research on models of friendly environmental policy.

Technologies for a Sustainable Economy
Strategic Foresight Statements

Air pollution

- Reduced toxic emissions from car exhausts through diesel catalysts, particulate traps, lean NOx catalysts or high precision combustion by 2006 to 2011 leading maximum ozone concentrations to 30% of 1990 levels by 2009 to 2017(J97, D98).

Chemical hazards

- Europe has a relatively strong position but the US leads on the understanding long-term effects exposure to harmful chemical substances and techniques to predict the fate of new and persistent chemical substances (J97).

Transport telematics

- Market penetration is generally very low, dues to segmented markets, lack of standards and interoperability, stand-alone systems and lack of a common vision guiding the deployment of a common architecture. (IPTS 1999) (ICSTI 1999) (UK 1999) (STF 2000)

Why are Technologies for a Sustainable Economy a potential topic for European research?

Direct link to EU Policy. Assessing and controlling risk from chemical substances requires knowledge of the environmental properties of chemical substances as well as mechanisms and strategies of how to deal with related uncertainties. Progress on chemicals policy is only possible if reliable and sufficiently rapid methods are available EU-wide to test the risk of chemical at reasonable cost. Data requirements in the dangerous substances directive may have to be extended to persistent and bio-accumulative properties. Methods for testing the endocrine-disruptive properties need to be developed.

Building on strengths. European leadership in many areas of sustainable technologies provides an entry point for building on strengths. An example is the energy industry (see Box 2) where a combination of political and economic factors has produced a broad industrial strength that is soundly based on technological leadership. Here the European research issue might be to build and extend this leadership by pushing forward towards practical implementation of an integrated low-emission energy system, such as a hydrogen-based economy.

Box 2: Building on Europe's strengths in the energy sector

Renewable renaissance: political and economic support for renewable energy in Europe outpaces any other region of the world. Europe is at the leading edge not only in the wind industry, but also in biomass (i.e. biomass gasification for gas turbines), solar photovoltaics, solar thermal heat and electricity, geothermal and small-scale hydropower. There is rapid growth in technology markets in such fields as photovoltaics (PV), wind, fuel cells, combined heat and power (CHP) or electricity storage systems. Europe installed more wind electricity capacity in 1998 than all countries of the world combined. Member States, such as Denmark, Austria, Finland and Sweden have already exceeded the target of 12% of all primary energy from renewables by 2010. This leads to competitiveness: Denmark provides 75% of global wind turbine exports.

Coal production remains important, with coal reserves and a historical lead in coal technology, Europe continues to place emphasis on cutting edge technology development. Technologies include clean coal (super-critical coal (PFC), integrated coal gasification with combined cycle, advanced coal cycle). From cutting edge fluidised bed combustion, to supercritical gasification, Europe invests more per capita in top line, clean coal technology than any other region of the world.

Evolutionary nuclear: European firms are some of the most competitive nuclear technology exporters in the world. While some European Member States downplay or reject the nuclear option in (e.g. Austria, Italy, Denmark, Sweden and Germany), the industry is still a major player in the EU energy economy. European Member States and the European Union spend more, per capita, in public research on nuclear than any region of the world. As political opposition to nuclear builds in the EU, the CEECs and North America, Asia and other emerging and developing economies are becoming Europe's major nuclear export partners. Nuclear arguably represents a logical energy technologies to address concern for emissions. Major research on 'break through' technologies continue (i.e. so-called 'new or evolutionary' nuclear).

Building critical mass: The European position is strongly shaped by the heterogeneity of the region as compared to the two other major regions (North America and Japan). The major challenge relates to issues of how to integrate telematics applications for transport on a European scale rather than on a national or regional scale, giving strong basic research and SMEs a higher exploitation potential. A challenge could be to build on the success of GSM by using it as a backbone and adding services in a language-independent manner.

There is room for activities on a European level to support environmental technology, design, and method transfer and knowledge diffusion with specific attention to SMEs and less favoured regions[13]. A strong demand-pull for such technologies is a key factor for their development, which points to a role for co-ordination with environmental policy.

[13] Tuker et al. (2000) "Eco-design: European State of the Art" ESTO

Current national foresight studies (J97) see Europe lagging behind the USA in research on space technology applied to global environmental issues. Strengthened international co-operation with the global partners in such research is one factor to improve the European position (D98), another one is to develop further European large-scale efforts in areas such as remote sensing and modelling of complex systems.

Building future leadership positions. There is a need to build research synergies between relevant disciplines and methodologies in the social, medical, technological, occupational, public health and environmental domains. For example the five year assessment of the Energy, Environment and Sustainable Development Programme (FP5)[14] identifies a shortage of socio-economists with appropriate experience to work on environmental issues and recommends the formation of European Centres of excellence in environmental socio-economics. Priorities might include:

- Understanding large-scale ecosystem management,
- Integration of technology-environment policies
- Assessing exposure to chemical, biological and physical environmental hazards, including occupational settings.
- Combined Urban and traffic management systems

Such integrative approaches are a particular strength in some European countries (Sweden, the Netherlands, Germany) and may provide a basis for global leadership in the area of implementation of complex systems.

Inherently transborder issues. Atmospheric and water pollution emissions are often transborder issues and Europe will have to often has to draw upon research that supports the development of common international positions and agreements within the EU. This points towards combined approaches on issues such as technologies to control car traffic emissions (a major source of air pollution problems) or biotechnological, chemical or physical processes to effectively clean up pollution from oil spills of tank ship accidents.

Also, cross-border issues are characterised by complex interactions among private firms, NGOs, communities, nation-states and other interest groups. For global issues (e.g. climate change) a leading edge position of European science is important to give support to policy

[14] http://www.cordis.lu/fp5/5yr_reports.htm see also OECD (1998) 'Technology Foresight: environment Related Issues' of the Working Group on Innovation and Technology Policy, DSTI/STP/TIP (98) 11 on the need to better understand the links between technology and environmental policy.

III. Technologies for a Sustainable Economy	Key: Main correspondences to Mega Challenges Knowledge ■ S. Development ■ Health ■ Mobility ■ Europe ■
1. ■ ■	**Sustainable Production & Consumption** Eco-efficiency demonstrators & experiments; technology enhanced service models that lead to dematerialisation; revalorisation-friendly product design; separation, reclamation and recovery techniques.
2. ■ ■	**Socio-Technical System Design for Sustainability**: systemic multi-factor design tools, organisational research on interfacing systems and structures, complex systems and modelling, research on economic incentives/pricing systems; new holistic forms of urban governance with citizen participation in decision-making
3. ■	**New Models of Transport Infrastructures**: high speed rail, transhipment and material management facilities, intermodality solutions, new transport forms designed to meet urban demands; Safety Techniques: integration of passive and active safety elements
4. ■ ■ ■	**Logistical and Control Systems**: traffic management, fleet management, engine control systems, convoy driving, passenger information systems, distributed dynamic databases and middleware, standards integration systems, GPS, tracking and tracing, Safety Techniques
5. ■	**Sustainable Energy Management and Supply Alternatives**: Safe efficient generation, transport, storage, transmission & utilisation; new infrastructures for electricity and fuels (incl. H_2), deregulated market logistics & demand management, sustainable energy services and utilities design, socio-economic and pre-normative research for policy & technology diffusion. New renewable fuels & sources of energy (solar, photovoltaic, wind, bio-energy, geothermal), the H_2 economy, embedded generation (micro-turbines, hybrids, fuel cells…), clean electricity (zero emission power plants, CO_2 capture & sequestration), alternative & evolutionary nuclear energy, nuclear waste management
6. ■ ■	**Management & Mitigation of Climate Change and Eco-system Threats** Eco-system & biodiversity preservation, experimental platforms for the management of ecosystems as natural resources, carbon sequestration, prevention of floods and other man-made and natural disasters, prospective analysis of socio-economic repercussions
7. ■	**Observation, Assessment, and Modelling of Climate-Change and Eco-systems** <u>risk and precaution-related research</u> – anticipation of climate-change effects, of natural & man-made disasters, environmental geographical information systems, remote sensing, modelling of complex natural and anthropogenic systems

S&T Area IV: Social Science in Support of Building Europe

Definition (key trends/opportunities). Europe as a whole is confronted with a number of challenges that originate decisively from the socio-political realm. An enlarged Europe needs new requirements for an efficient European multi-level governance structure and it needs to define its borders to the East and South, developing new concepts for the relationships with neighbouring countries. Demographic change and migration will be key challenges for both European and national policy. External relations are developing into an ever more important concern of the Union, in need of underpinning by research.

Europe will be then confronted in the future with a higher degree of diversity within its borders, culturally, politically, and economically. The diversity of values may in the future be complemented by growing intra-European mobility of people & the media.

Changes in the regional balance and cohesion of Europe, especially as they are affected by technological developments in ICTs will create a significant requirement for supporting socio-economic research. Together they raise important questions about the creation of an effective internal labour market in Europe.

Both social sciences and humanities have the potential to provide insights and thus support to policy in order to help build Europe, especially by working across disciplinary boundaries.

Key research fields:

While some of the relevant research fields relating to Building Europe cut cross the other main S&T areas, there are nevertheless a number of distinct social science issues to be addressed in the Europe:

- Governance models: Europe's multi-level governance approach has turned into a model for other world regions, but is in need of upgrading. New opportunities arise from e-governance elements, from an extension of participation and a reinforcement of active citizenship.
- Values research: Common values and priorities are critical to building an open and democratic Europe, which has achieved a balance between common approaches and subsidiarity, ethical priorities, or the issues of social cohesion vs. economic efficiency.
- Conditions for a stable, open and multi-cultural environment in Europe building on the tolerance and respect for other cultures. The origins of xenophobia and ways to overcome them need to be explored to maintain Europe as an attractive place to come to, for foreign business and workers as well as for tourists.
- Origins of and remedies to extremism and crime: In order to counteract extremism and crime, a better understanding of its origins and motivations is needed to develop counteracting policy strategies.

Social science & European Integration
Strategic Foresight Statements

- Stability in EU depends on stability of new members (IPTS00)
- Attitudes towards representative democracy are changing (CdP 99)

- European social models: A well-developed social system is a safeguard against certain forms of extremism and crime. In fact, Europe's social models are regarded in many foreign countries as the way to follow. Within Europe comparative analyses of the different ways to address social challenges should be carried out, as well as mixed qualitative-quantitative explorations of the future.
- Social and regional cohesion: This remains one of the key concerns of Union, which will be augmented significantly by enlargement. Regional development strategies and the lessons to be learnt from past experiences need to be updated.
- Supporting cultural diversity: how to cope with the growing pressure on European diversity resulting from a globalised and increasingly homogeneous media content and culture production (c.f. film industry) Specific example: European cultural content documentation initiative, i.e. a fairly large scale project to provide electronic access to a large range of cultural achievements in Europe
- Patterns, motivations and trends in (cultural) consumption: With diversity being a key feature of Europe, the patterns of cultural, but also other forms of consumption are an important input to better customise public and company policies.
- Building a networked social research infrastructure: i.e. data-bases, data collection. This is important to underpin European policy. For example, a network of

European (and non-European) study centres on specific regional themes (e.g. Asian or Latin American studies, etc.) would create a broader pool of competencies on which European policy could draw.

In several of these research fields, comparative analyses are needed to learn about the possibilities and limitations of transferring experiences across national borders, and even aggregating lessons at the European level. Others are more amenable to building or networking research infrastructures. Most areas of research would benefit from a process perspective.

Why is Building Europe a potential topic for European research?

Under the terms of the European Treaties research a range of actions lend themselves to being carried out at European level. They are almost by definition a candidate topic for European level research.

More specifically, most social science research areas mentioned aim to **support EU policies**. In others, **economies of scale** can be gained from pooling and networking centres of complementary expertise (excellence) and related infrastructures. This enables also the **sharing of knowledge and mutual learning**, but provides also a broader competence base on which European policy can draw.

Encouraging a long-term horizon, tackling complex issues and **Direct link to EU policy.** Social science research on values and governance brings also issues to the forefront that encourage thinking about the long-term horizon and the complexity of building Europe. Such a forward-looking approach is also able raise new issues for policy that may be ignored in other areas of research and policy. It also helps spotting changes in demand, pointing to new social and economic opportunities.

Developing public confidence. Two further justifications are of particular relevance in relation to governance issues, namely first the wish to support and empower citizens in all their activities across Europe. Secondly, social science research, especially in a comparative perspective, can help build a European awareness and understanding of both commonalities and differences.

IV. Social Sciences in Support of Building Europe	Key: Main correspondences to Mega Challenges Knowledge ■ S. Development ■ Health ■ Mobility ■ Europe ■
1. ■ ■	**Social science/humanities Implications of The EU Project** governance, citizenship & participation; cohesion Values research; extremism and crime; multi-cultural environment in Europe; principles of political systems

Part 2: Cross-cutting Science & Technology Enablers

S&T Area V: Gene Technologies

Definition (key trends/opportunities). Transition to the post-sequencing genomics era will see the development and implementation of new therapies, diagnostic tools and improved health-management strategies. The growing knowledge on the function of human genes and the role of these genes in maintaining health, causing diseases and determining the ageing process will have a high impact on human health, health care system structure and organisation, and pharmaceutical sector development. Advances in plant and animal genetics will modify agriculture and husbandry techniques, with new environmentally sound production processes.

Major trend breaks:

- The completion of human genome sequencing will radically change the pharmaceutical paradigm, from "bio-chemistry" to "pharmaco-genetics".
- Developments in bio-informatics, broadly defined as computer-assisted data management tools, to store, access and analyse the data generated from investigation of biological phenomena.
- Production of plants and animals with pre-determined genetic characteristics (pest and drought resistant, with high feed conversion index, etc.)

Key research fields:

- Proteomics: mapping of protein expression in order to detect differences between the proteome complement in healthy and diseased states; analysis of functional interactions between proteins by isolating and characterising the components of protein complexes; exploration of pathogen genomes; analysis of protein modification.
- Development of transgenic animal models to permit experimentation of new gene technologies.
- Molecular epidemiology: especially on multifactoral diseases where gene therapies have fewer applications.
- Pharmaco-genetics: improvements in disease targeting, prevention and diagnosis will determine a reduction in societal and economic costs related to health care.

Gene-Technology Strategic Foresight Statements

- Genomic technologies will enable targeting diseases at gene, correcting aberrant gene expression, compensating for loss of gene function or selectively blocking a specific gene (UK95; F00; IR98).
- People will receive individual risk assessment for some diseases based on genetic screening and lifestyle measures (UK95).
- Technologies for preventive medicine and diagnosis will reduce the frequency of misdiagnosis and societal costs of wrong treatments (US98).

- Creation of gene sequence and proteins structure databases where the vast amount of data is stored in a standardised format and accessible to the global research community.
- Development of software for analysing sequences and predicting protein functions. Creation of applications able to accurately simulate sub-cellular processes and to model the detailed temporal and spatial interactions between gene products in a living cell, giving insights into diseases processes and potential therapies.
- Mathematical models and algorithms to simulate complex intracellular processes, such as signal transmission and metabolic pathways, and to analyse the whole amount living organisms (plants, fungi, insects, developing embryos, etc) in order

to study metabolite transfers between cells and the establishment of cellular (neurological) connections.

Why are Gene technologies a potential topic for European research?

Development of mutual learning and knowledge sharing. Functional genomics requires unprecedented levels of collaboration between biomedical scientists, computer engineers and computational biologists both in academy and industry. Top level skills in all these research fields may be better achieved if the issue is approached at European level.

Large-scale high-visibility projects. In all cases when equipment is too expensive for a single country, e.g. synchrotron, high field Nuclear Magnetic resonance, high voltage electron microscopy, super computers (especially for mass spectrometry) with high speed and high data handling capacity.

Building critical mass and exploiting economies of scale. To cut down on replication of transgenic facilities and ultimately the number of animals used. Establishing genes and tissues banks at EU level, storing EU great biological diversity. To perform massively parallel genetic data processing.

Developing public confidence and **Protecting individual citizens.** Ethical, regulatory and legal issues related to functional genomics, such as privacy and security in the use of large collections of biological material and masses of individualised data, will need an EU-wide approach.

Direct link to EU policy. Problems arising on patenting of gene sequencing will need EU regulation policy.

V. Gene technologies	Key: Main correspondences to Mega Challenges Knowledge ■ S. Development ■ Health ■ Mobility ■ Europe ■
1. ■ ■	**Post-genomics and bio-informatics** Proteomics; Transgenic animal models; pathogen genomes; Molecular epidemiology (especially about multifactoral diseases); Integrative biology; Pharmaco-genetics; data management tools; database and sequence analysis software development: research on IPR issues.

S&T Area VI: Information and Communication Technologies

Definition (key trends/opportunities). Information Society Technologies face serious trend breaks in the coming years. Three main technological dimensions can be identified as structuring the path: the *ubiquity of computing* (driven by micro electromechanical system [MEMS] design advances and Moore's Law[15]), the *ubiquity of communications* (driven by Metcalfe's Law[16]) and a correlated development that will enhance the functionality of ICTs in the form or *Intelligent User Interfaces*. [17]

[15] Moore's law predicts that the density of transistors on a chip will double every 18 months.
[16] If there are n people in a network, and the value of the network to each of them is proportional to the number of other users, then the total value of the network (to all users) is proportional to n^2 - n.
[17] In the recent pronouncements of the Advisory Group to the IDT Programme these three trends have been seen as on track to combine in the form Ambient Intelligence (ref.)

These three dimensions are related to expectable trend breaks in the coming years:

- The possible slowing down of Moore's Law (VLSI based on CMOS) by 2015 and the search for new ways (nanotechnologies) to continue to benefit from the very strong productivity gains related to *miniaturisation* of information processing and storage as the 100nm threshold approaches.
- Massive demand for bandwidth fuelled by rising multimedia connectivity (next generation Internet, digital TV, webphones/UMTS)
- Quantum leap in complexity due to the very fast rise in the number of devices and users on-line, rising functionality and interconnection of software, greater intelligence in devices, networks with implications for dependability of computer architectures, network management and communications systems and software.
- A strong move towards people-centric and mass-customised ICTs, depending on *software and artificial intelligence breakthroughs* to tame ICTs so that they are fit for widespread use.

Key research fields:

- Continued miniaturisation: micro, and moving towards hybrid micro-nano and nano devices, to permit ubiquitous computing to be physically unobtrusive. Interconnecting the micro and nano levels is likely to be an on-going challenge, particularly on commercialisation. Tiny footprint operating systems and specialised circuits as cheap and fast alternatives to VLSI chips. New manufacturing techniques need to be developed to support these scales of miniaturisation.
- Ubiquitous computing: wide embedding of processors, sensors and actuators and micro-systems calling for new patterns and directions of circuit design such as zero instruction set computing. Greater integration of bio, chemo, optic and silicon domains.

Information and Communication Technologies
Strategic Foresight Statements

- 0.1μm technology to be commercialised by 2000 (J97), or 2005 (UK00)
- Magnetic memory hard disk of 1000 Gbits per square inch by 2017 (J97)
- Systems on a chip with processor, storage 1 Gbit by 2002, 1 Terabit by 2010 (UK00)
- Lightweight 24 hour batteries 2015(UK95)
- Error free large scale software 2012 (J97)
- High security NG Internet 2003 (J97)

- Tangible user interfaces: Embedding of systems into everyday objects including research on emergent uses leading to new production possibilities and service opportunities. Joint engineering and ethnographic research to investigate 'emergent uses' of augmented objects.
- Ambient power sources: very widely distributed processing will require zero, very low or smart power solutions, not all objects containing batteries of electricity ports.
- High bandwidth communications networks, i.e. fully optical networks including photonic signal processing and new ways of handling spectrum scarcity.
- Seamless interconnection of networks based on the development 'service level platforms' offering transparent integration of different communications systems, devices and services.

- Ad-hoc configurability: Computing and networking architectures will permit on the fly configuration of devices and services and the ability of providing bandwidth on demand.
- Cognitive and human systems modelling: breakthroughs for instance through the development of self-organising intelligent agent systems and middleware rather than the domain-by-domain approach of today. Emotional bandwidth flexibility, i.e. permitting users to gain the level of required resources they need for any particular activity.
- Reliable handling of complex systems (in networks, software, cross-media and technology functionality and human behaviour): includes dependability, fault tolerance and graceful decline. Will involve breakthroughs in software systems such as self-organising software, component-based software and libraries.
- Security and trust technologies: the surety that privacy and accessibility is at the user's discretion. Agent technologies that manage risk or exposure on a case by case basis.
- Humanised interfaces technologies: future developments in interfaces are expected to increasingly rely on smart materials, such as piezo-electrical devices, MEMs and shape-memory alloys, biosensor systems, etc. Further visions on ICTs favor "invisible" and "calm" technologies offering fully humanised interfaces.

Why is Information Society Technology a potential topic for European research?

Information and Communication Technologies (ICT) are not only important in their own right they are pervasive as enabling technologies in most of the other technology sectors (see the sections on knowledge technologies, transport and mobility, health and gene technologies). In short, the international competitive position of Europe depends on being in the vanguard of these technologies on a broad basis.

There are opportunities to build on **Europe's existing industrial and research strengths** in these areas such as mobile communications (Bluetooth, GSM, GPRS and UMTS), portables (PDAs) and the development if not commercialisation of transport telematics. Also strong are design of real world interfaces, communications, sensor systems, microsystems, embedded systems, and the design of physical objects (augmented appliances, clothes, furniture).

These strengths position Europe well for the coming developments in ubiquitous computing, communications and intelligent interfaces. Opportunities are also expected to be strong in new markets for producers of all sorts of physical and tangible products and services based upon the development of "augmented objects" or 'smartifacts' that communicating intelligence build into them. However, weak commercialisation of complementary technologies agent technologies, middleware, displays, speech recognition and e-commerce based services may reduce the advantage of this current leadership profile.

The building of an e-Europe is also likely to have strong social and economic research implications as regards **individual citizens, public confidence and building of Europe**. In the coming years policy research will particularly focus on the societal aspects of the opportunity to build a more people centred European upgrade to the 'dot.com' version of the Information Society that holds sway for the moment.

VI. Information & Communication Technologies	Key: Main correspondences to Mega Challenges Knowledge S. Development Health Mobility Europe
1.	**Enabling ICTs for Knowledge Systems**, core ICT components & devices and industry specific applications/ platforms/ content; Fixed and mobile access networks and devices, Software engineering, methods and products;
2.	**Ubiquitous Computing, Ubiquitous Communications & User-Friendly Interfaces** Ambient power sources; Miniaturisation; Sensors, micro-systems, embedded systems; Complex networks, software, functionalities, behaviour; Dependability, fault tolerance, graceful service decline; Computing and networking architectures; Cognitive and human systems models (Artificial intelligence) and understanding of the cognitive and social effects of the wireless society. Design and development of augmented objects

S&T Area VII: Advanced Materials

Definition (key trends/opportunities). New materials are strategic. They are fundamental enablers of almost all other enabling technology areas (especially ICTs and biotechnologies). They provide the basis for innovations in system technologies such as transport, energy, defence and aerospace. In this project, experts drew particular attention to two issues: 1) sustainable materials and recycling issues for complex components, and 2) smart or intelligent materials.

Particularly important trends are:

- The moves from passive structural and active functional materials to multifunctional materials and smart materials.
- The need for materials that lend themselves to sustainability requirements - longer service life, reusability, biodegradability.
- New materials processing techniques such as molecular design, nano-level[18] self assembly, three dimensional printing.
- Radical changes in demands on materials in health care (e.g. biocompatibility, biomimetic materials for prosthetics), in construction, automobiles and aerospace (e.g. lighter and stronger materials for frames), in computing devices (VLSI, optical processing, quantum computing).

Advanced Materials Strategic Foresight Statements

- Rising importance of intelligent materials - for process control inspection & Security (S00); piezo- & ferro-electric and magnetic materials, and 'functional' textile fibres (F00)
- Emerging material synthesis biotechnologies for biopolymers & biomimetics for minerals (F00)
- Separation technology, and overhaul & repair technology are increasingly critical (US98)
- Micro-biological materials: control of leachates from wastes 2015 (UK 95)
- Lower cost optic fibre links in 50% EU homes (J97/UK95)
- Solar cells with conversion efficiency >30% (UK95/J97)

Key research fields:

The key research fields identified, are illustrative of the two particular issues mentioned above (sustainable materials and Smart materials).

[18] Nanoscience and nanotechnologies are dealt with elsewhere separately.

Environmental and sustainability concerns dictate a set of research tasks relating to the steady rise in waste.

- Sustainability: limiting the use of matter and energy, lowering waste outputs, ecosystem compatibility and biodegradability and the recyclability of complex multi-material products and systems, such as electronic devices, household appliances and vehicles

Similarly motivated research is required to tackle the issue at the root via technology for the production and use of more environmentally friendly materials.

- Renewable materials: biomass for energy, agricultural crops for oils and lubricants, bio-plastics and bio-oriented materials, glues and fibres from marine organisms, extending service-life and recycling rates of wood-derived materials, are some of the examples that were raised.

For smart, functional materials, there is a host of technical issues requiring research depending on the type of material, the breakthroughs required, the intended device and ultimate application. The following few themes is no more than an illustrative sampling relevant to smart biomaterial applications.

- More efficient and user-friendly materials for health-care applications with longer lifetimes.
- Resistance to corrosion and chemical effects for longer life and sustainability
- Smart materials with programmable responses to specific stimuli, e.g. smart ink, coded biomaterials/ biosensors that respond to specific biological stimuli.

Why is Advanced Materials a potential topic for European research?

Materials research on the whole in Europe, is in a relatively good position internationally. The field is dominated by industry, and is characterised by a relatively mature range of technologies which follow an autonomous path of incremental innovation aiming at substitution, dematerialisation, increased functionality, etc.. Hence, we have to look carefully at the field with a view to identifying potential European priority research themes.

Developing strengths in key areas and **Bridging gaps in the innovation system.** Advanced Materials Research must be seen as a small subset of this vast field where the most advanced materials developments are highly dependent on basic research and where just a few leading firms are in a position to incorporate state-of-the-art materials into niche market products before wider applications are found - e.g. defence and aerospace applications, high-tech sports equipment and vehicles, etc.. Europe's position here is more vulnerable, especially given the fragmentation and dispersion of the research carried out by fundamental and academic R&D organisations and the poor integration of their research efforts with those of firms.

Direct link to existing EU policy. The sustainable materials challenge (i.e. matching business competitiveness with sustainability) is EU-wide requiring both concerted approaches on setting standards and on developing new solutions regarding the supply of goods, producer responsibility, recycling and disposal of wastes - especially of recent generations of complex materials and products where materials are mixed and combined often down to molecular level. In principle, this is an area where Europe could capitalise on the existence of an innovation-friendly policy environment, and overall leadership in the recycling and re-use sphere. There are economies of scale to be gained with technologies for the processing of waste streams, as well as in promoting new developments and technical innovation in the area of renewable materials for energy production and other industrial-scale applications. These can be attained more easily at European level, and can also aid the cohesion objective by developing complementary competencies and dependencies between regions whose industrial materials consumption requirements and potential production capacity may be inverted (e.g. for biomass).

Development of mutual learning & knowledge sharing and **Large-scale high-visibility projects.** For smart materials which are at the forefront of functional materials research, European level action would help to compensate for the lack of coherence and fragmentation that characterises an otherwise fairly good level of scientific research. The absence of strong and well articulated demands from military and dual use areas is a systemic weakness in Europe with respect to the US. There would be good benefit derived from a networking of the smart materials research efforts scattered across the continent, aiming for example, at the attaining of a critical mass in some specific application areas (such as large civil engineering structures, aerospace, biomedicine), which would constitute demonstrators and test-beds for diffusion of the technologies into other domains.

VII. Advanced Materials	Key: Main correspondences to Mega Challenges Knowledge ■ S. Development ■ Health ■ Mobility ■ Europe ■
1.	**Sustainable Materials -** recovery, re-use & recycling of complex materials, new renewable biological/ agricultural material feedstocks, fibres, lubricants, etc.; re-use of materials in renewing the built environment
2.	**Functional Intelligent Materials** - new alloys, plastics, ceramics, composites, for health-care and industrial applications. more efficient and user-friendly with longer lifetimes. are more resistent to corrosion and chemical effects; programmable responses to specific stimuli. E.g. coded biomaterials with specific responses to specific biological environments.

S&T Area VIII: Nanoscience, Nano & Precision Technologies

Definition (key trends/opportunities). Nanoscience, as a whole new emerging transdisciplinary field drawing on physics, chemistry, medicine and biology, constitutes in its own right a major new trend. It has a significant <u>materials</u> science and engineering component covering ultrathin layers, manipulating material and building lateral structures down to atomic scale and nanomaterial and molecular architectures with novel macroscopic properties. In terms of the array of potential nanotechnologies[19], important '<u>systems</u>'-related challenges are also raised regarding integration and interconnection different nano-scale features to form functional components.

[19] Micro-invasive surgery and implants, artificial retinas, artificial antibodies, new lasers, millimeter wave components, nano-porous cavities and tubes for filtering, adsorption and storage of hydrogen, membranes for fuel cells, catalysts, nanodispersions for coating and hardening, layers for LCDs, antireflex surfaces, photovoltaics etc.

Key research fields:

Nanotechnologies are viewed by many commentators and policy makers to hold the potential for a new industrial revolution becoming as or more pervasive than today's ICTs. The field is dispersed across a wide range of disciplines and application areas, with some applications such as nanophase composite materials already on the market. However, the great potential envisaged for this area is still a long way off, and will depend on some very fundamental developments in the area of atomic level assembly of structures, the integration of different components into applicable systems and the scalability and reproducibility of laboratory-level demonstrations.

> **Nanoscience & Nanotechnology Strategic Foresight Statements**
>
> - Europe is strong in science of nanocomposites but weak in industrialisation [expected 2005] (F00)
> - First Nano 'molecule assemblers' by 2010, bucky fibres by 2020, nanocomputers by 2040 (F00)
> - Hydrogen produced via artificial photosynthesis by means of molecular level material synthesis (S00)
> - Practical use of biochip devices (memory density 10^{12} bpcm^2) (J97)
> - Practical use of processing technologies with Å and femto-second scale resolution 2009 (J97)
> - Mass processing of patterns <10nm 2013 (J97)

A sampling of some of the research themes highlighted in this project includes:

- *Nano-scale materials manipulation*: atomic scale layers & lateral structures; writing techniques, particle beams, self-organisation, ultra-precise surface figuring, analysis techniques of vertical/ horizontal structures, boundary layers & surfaces; complex combinations of mechanical, optical, electrical or chemical characteristics, of organic, inorganic or biological molecular structures; development of Extreme Ultraviolet Lithography - (this latter, which would be a bridge from current microelectronics to future nanoelectronics, could constitute a large-scale project of true European dimensions!)
- Nano-structured materials: nanomaterial & molecular architectures with novel macroscopic properties;
- Systems research aspects: integration & interconnection of different nano-scale features to form functional components, nano-scale devices & systems.

Why is Nanoscience, Nano & Precision Technologies a potential topic for European research?

Developing on strengths. This is a new area of science and technology with very many potential applications and a very high market potential. It is very important to underpin the competitiveness of existing business sectors in Europe as nanotechnologies find their way into a vast range of potential applications, as well as to enable the emergence of whole new applications and areas of business. For example,

- in the area of ICTs as certain nanotechniques hold the potential to further extend Moore's law beyond its presently foreseeable limits within the current Silicon semi-conductor paradigm.
- in the car industry nanotechnology will be of crucial importance for all kinds of sensors, actors, engine and emission control, displays, reduction of lubrication and wear, alternative propulsion systems, coating and even painting.

- direct market volume of microimplants and sensors in the area of biology and medicine in the early 2000 will be in the range of several billion Euros[20].

For Europe to be a strong player, in what for the US Office of Science and Technology will give rise to the next industrial revolution, it must to build multidisciplinary competence base perhaps based on the development of highly specialised complementary expertise profiles in different parts of the EU.

Direct link to EU policy and **encouraging a long-term horizon.** It is also very important for Europe to reach common standards in nanotechnologies. Success on the world markets for European products is only possible if, accompanying R&D, a standardisation process is started. European-level research activity can provide the knowledge and reference information base for standards issues at the necessary and right time.

VIII. Nanoscience, Nano & Precision technologies	Key: Main correspondences to Mega Challenges Knowledge ■ S. Development ■ Health ■ Mobility ■ Europe ■
1. ■ ■	**Nano-scale manipulation** Atomic scale layers & lateral structures (writing techniques, particle beams, self-organisation,..), ultra-precise surface figuring, analysis techniques of vertical/ horizontal structures, boundary layers & surfaces; Extreme Ultraviolet Lithography (affordable 11 nm or 13 nm x-ray sources, x-ray optics, etc.)
2. ■ ■ ■	**Novel Materials** nanomaterial & molecular architectures with novel macroscopic properties; nano-porous cavities and tubes for filtering, adsorption and storage of hydrogen, membranes for fuel cells, catalysts, nanodispersions for coating and hardening, layers for LCDs, antireflex surfaces, photovoltaics etc.
3. ■ ■ ■ ■	**Nanotechnologies & systems** integration & interconnection of different nano-scale features to form functional components, nano-scale devices & systems; complex combinations of mechanical, optical, electrical or chemical characteristics, of organic, inorganic or biological molecular structures; potential technologies in medicine, precision engineering, electronics, etc. - micro-invasive surgery & implants, artificial retinas, artificial antibodies, new lasers, millimetre wave components

S&T Area IX: Complexity and Complex Systems

Definition (key trends/opportunities). Complexity research using approaches based on biological rather than mechanistic metaphors has emerged as a promising way to better understand the natural, technical and social systems, and to better design, assess and manage them.

Features of complex systems: Typical features of complex systems include large number of components and interactions, the multi-level and multi-actor character of the phenomena in question, their dynamic and non-linear behaviour, the time-criticality of actions, the inherent uncertainty and unpredictability of their future evolution/transformation, and the huge volume of information requiring simultaneous processing. As a consequence, flexibility, reconfigurability and robustness are critical characteristics of complex systems.

[20] The world wide market of the chemical supply industry for nanophase ceramic deposits is already in the range of 25 billion Euros. The market of optoelectronic components already exceeds 1 billion Euros. Components in the ICT industry (storage devices, disks, lasers) sum up to more than 40 billion Euros.

Dealing with complexity: The critical challenge in complex systems research will be to bridge the gap between fundamental research solutions for deal with the aforementioned features, and the requirements raised in several applied areas where complex modelling is regarded as a key source of insight (e.g. climate modelling, ecosystems under stress, interactions between social and natural systems, financial systems, transportation, energy and water supply, town and regional planning, engineering and software development).

Applied complex systems modelling relies on large amounts of data and thus requires abundant computing power to process them.

In the end, complex systems research serves to inform either technology developers or decision-makers about strategies to mitigate undesired side-effects or achieving better system performance. The challenges to which complex systems research ought to offer responses are a) to improve the reliability of and thus the confidence in the systems, b) to "control" systems that operate in a context (open systems) such as those relating to the sustainability issue (ecosystems, social systems), and c) not only to understand existing complex systems, but also to design new ones.

Key research fields:

Basic understanding of systems in different important application areas: Complexity research puts emphasis on characteristics such as stability and control criteria, robustness and reliability of systems under changing circumstances, reduction to critical variables, sensitivity to different levels of analysis, interactions between system and environment, and information control. Improving the confidence in system modelling results will be decisive for their wider application in areas such as:

- climate modelling at different spatial levels,
- the behaviour of ecosystems under stress,
- interactions between social and natural systems,
- microbial ecology and its impacts on human health prevention,
- financial and socio-economic system behaviour,
- modelling of transportation, energy and water supply systems in their interaction with human activity,
- town and regional planning,
- engineering of large-scale technical systems,
- Software development and maintenance.

Complexity & Complex Systems Strategic Foresight Statements

- Error free large scale software 2012 (J97)
- Transport technologies are complex systems requiring multidisciplinary capabilities (IPTS00)

Complexity research interprets systems as being open and depending on a broad range of boundary conditions. This raises the necessity for a multidisciplinary approach, based on similar principles of understanding system operation.

Development of generic tools and components: Modelling, simulation and design of complex systems would greatly benefit from a component-based, modular approach and the development of appropriate languages for this task. Components should be developed for system design purposes and at different levels of application from specific to generic to be applicable to a range of problem areas. Care needs to be taken in avoiding the pitfalls of transferring specific solutions.

Computing infrastructure: Complex systems research requires the availability of massive computation power, and in some cases, specific hardware for simulation or interfacing with physical systems (heterogeneous simulation of embedded systems).

Data retrieval and system monitoring: To underpin applied complex systems research, large amounts of data need to be retrieved, in many cases via a continuous and systematic monitoring process across countries to detect changes (e.g. climate modelling, ecosystems, emissions, etc.). Intelligent retrieval techniques are needed to facilitate this. The problem is not only the "amount" but also the relationships. In many complex systems all elements are related and the problem is to reduce the interdependencies.

Management of complex systems: Complexity research aims in the end at either problem solving and informing intervention in systems, which can include maintenance, error-fixing and upgrading. Advanced scenario techniques and interactive decision support are critical to connect research with decision-making, supported by a sophisticated design of communication process and interfaces. Management systems also have to incorporate the normative aspects related to complex systems evolution, e.g. the sustainability orientation of complex system management. An obviously very important area related to complex systems is 'risk management' in view of the huge consequences that could arise from failures.

Why is Complex Systems Research a potential topic for European research?

Large-scale or joint efforts are required to develop the kinds of conceptual, physical and software tools needed to address complexity problems that are of a similar nature in many European countries. This can be achieved in different ways:

- Integrating existing, but insufficiently interconnected centres of competence in complex modelling. Europe has a good but scattered research base in complexity research, which is in need of both a better transfer of findings from basic to applied research and better networked efforts in individual application areas.
- Monitoring and data collection in a diverse range of locations as a knowledge pool and platform of exchange, that could also fulfil the function of a reference system. This is necessary due to the common character of the problems to be addressed, but also in order to monitor and scan the diversity of situations in different countries (e.g. of ecosystems, urban systems, etc.)
- Networking and sharing of computing power to carry out systems modelling experiments.
- In several industrial areas (e.g. aeronautics, space, petrochemicals, pharmaceuticals, automotive), Europe has solid track record in providing solutions to complex tasks. Reinforcing the capacity in complex systems research could strengthen the competitiveness of these industries.

Complex systems research is also important to underpin policy development at European level, e.g. in areas such as transportation, energy and climate, agro-ecology systems, etc.

IX. Complexity & Complex Systems	Key: Main correspondences to Mega Challenges Knowledge (cyan) S. Development (yellow) Health (red) Mobility (green) Europe (blue)
1. (yellow, red, cyan, green)	**Better understanding of complexity**: stability, control, reliability under changing circumstances, improving confidence in systems modelling; sensitivity analysis
2. (yellow, red, cyan, green)	**Generic tools and components** modelling & design, simulation, modular approaches for system design, and both specific and generic components for applications
3. (yellow, red, cyan, green, blue)	**Computing infrastructure** massive computation power, hardware for simulation, infrastructure & platforms
4. (yellow, red, cyan, green, blue)	**Data retrieval and system monitoring** tools for dealing with vast amounts of information retrieval and collection, intelligent retrieval, reducing interdependencies (the butterfly effect)
5. (yellow, red, cyan, green)	**Management of complex systems** Reliability and dependability; self-organising, self-repairing systems, risk management