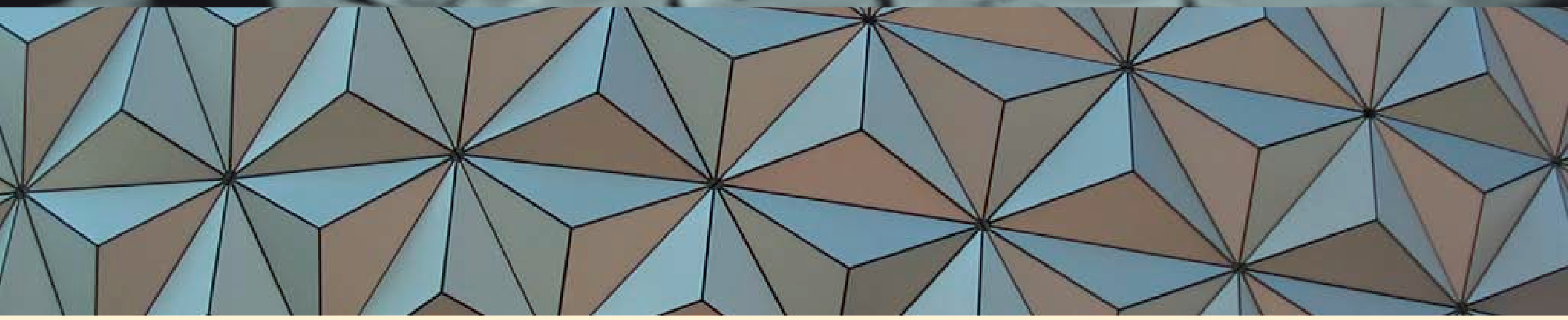

Report: Review of science and technology foresight studies and comparison with GTS2015

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Report: Review of science and technology foresight studies and comparison with GTS2015

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Executive summary

At the request of the Danish Agency for Science, Technology and Innovation, DTU Management Engineering reviewed a number of science and technology foresight studies and subsequently compared them with the GTS2015 catalogue. The result of this work is intended as input for an international assessment of the Danish GTS system (a group of independent Danish research and technology organisations). This report is a separate study undertaken to support and inspire the work of the international expert panel in its evaluation of the GTS system in Denmark.

The review was performed by scanning selected studies in the open literature. The studies reviewed were four international studies, three national-level studies and ten Danish-specific technology foresight projects, all conducted between 2002 and 2008. Each foresight study is presented here as a short summary. The studies were selected to cover international as well as national aspects and trends; their observations span technological fields and development trends. The technological fields identified in the studies are structured in this report in thematic classes related to 'technology and industrial push' and 'social demand pull'; the trends identified are structured using the STEEPV approach (social, technology, economics, ecology, politics and values).

In this report, we compare the foresight studies reviewed with GTS2015 from three different starting points: (i) the GTS2015 focus areas are taken one by one and briefly compared with the review results; (ii) the GTS2015 technological focus areas are compared at a general level with the technological fields identified in the studies review; and (iii) the GTS2015 trends are compared at a general level with the trends identified in the studies review.

The overall picture is one of good compliance between the issues selected for treatment in GTS2015 and the issues identified in the studies review. Especially technological fields and development trends with a high degree of attention and alertness in both national and international communities have a high degree of focus and representation in nearly all the reviewed foresight studies as well as in GTS2015. The highly mentioned technological fields are ecology, energy, health and ICT, and the highly mentioned trends are ecology, ageing society, innovation and knowledge society. In addition, the foresight studies reviewed give more attention to trends related to culture, values and the experience economy than GTS2015. The two experts interviewed for this report expressed the viewpoint that factors and aspects related to the understanding of culture and values should receive much more attention and awareness than they do today.

The comparison does not identify any particular Danish niches or strengths. Nearly all of the reviewed foresight studies on science and technology are at a rather high level of aggregation that provides 'a helicopter view' on technological and societal developments. This high level exercise does not leave room for treatment of specific technological issues and niches addressing the Danish occupational and business structure. The GTS2015 catalogue contains assessments and descriptions of Danish business strengths.

In an interpretation of the review results and the comparison with GTS2015, attention must be paid to the role of expectations. To some extent, the starting point for GTS2015 was FORSK2015, and the input for FORSK2015 was to some extent inspired by foresight projects and other kinds of future studies. Looking across the foresight studies reviewed, it is apparent that one study is often used as a source of inspiration for other foresight exercises. In this way, expectations can be replicated from one study to another, blurring their origin and perhaps also without the expectations themselves being questioned. Hence, critical reflections on the role of expectations are needed before decisions can be made based on interpretations of the results.

2. Introduction >

The Danish Agency for Science, Technology and Innovation asked DTU Management Engineering to conduct a review of a number of science and technology foresight studies; we reviewed these studies and then compared them with the GTS2015 catalogue. This exercise is intended as input for an international assessment of the Danish GTS system. This report is a separate study undertaken to support and inspire the work of the international expert panel in its evaluation of the GTS system in Denmark.

2.1 Aims of the study

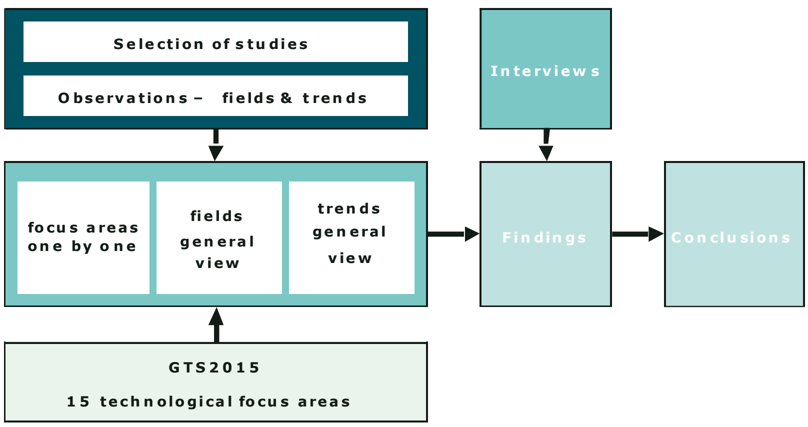
The aims of the study were:

- to provide a picture of the future need and demand for technological services in Denmark based on generic technological domains and development trends.
- to identify uncertain and significant drivers of change with an impact on the need and demand for technological services in Denmark.
- to inspire and support discussions and reflections on plausible development paths for technological services in Denmark within a time horizon of ten years.

2.2 Report structure and project design

The diagram shows the overall design of the project. The main input is the review of selected foresight studies and the 15 technological focus areas presented in the GTS2015 catalogue (GTS, 2008). The studies reviewed on the one hand and the 15 technological focus areas on the other were compared from three different perspectives: a) each focus area was briefly compared with the observations from the review, b) the GTS2015 focus areas were very generally held up against the technological fields identified in the foresight studies reviewed, and c) the GTS2015 trends were very generally compared with the trends identified in the studies. Furthermore, interviews with two external experts provided a significant contribution in casting a critical eye on the findings.

Figure 1. Project design.



The report contains the following:

- Chapter 3 presents a short definition in Danish of the concept ‘technological service’.
- Chapter 4 contains some theoretical and methodological reflections about foresight, transdisciplinarity and expectations, and possible influence on and consequences for the strategic scanning exercise.
- Chapter 5 presents the strategic scanning of science and technology foresights performed and contains short summaries and quotations from each foresight study included in the review. The presentations are rather compact and can be heavy reading.
- Chapter 6 summarizes the outcome of the strategic scanning in terms of technological fields and development trends.
- Chapter 7 presents a general comparison of each of the 15 GTS technological focus areas with the results of the studies review. The results of this comparison were discussed with two external experts and their viewpoints are presented.
- Chapter 8 contains the discussion of results.
- Chapter 9 contains the list of the references used.
- Appendix A is a summary of top five topics from the Japanese Delphi study.

2.3 The Innovation Systems and Foresight section at DTU

The Innovation Systems and Foresight section is part of DTU Management Engineering at the Technical University of Denmark. The aim of the section is research, methodology development and consultancy within strategy, decision support and policy making in science and technology, with a special emphasis on strategic and technology foresight combined with innovation systems studies. The section draws on a cross-disciplinary theoretical platform combining innovation system studies, strategy, systems studies and STS (social studies of science and technology). The main technology domains include energy and environment technologies and emerging technologies (nanotechnology, robotics, green bio/agro, etc.) The key target groupings are science and innovation policy makers and larger firms and industrial sectors.

3. Technological service: Concept

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The purpose of this section is to provide a common understanding of the concept ‘technological service’, which includes consultancy, innovation and development, business development, testing and certification, simulation, early warning and sales.

Ved teknologisk service forstås forskning og udvikling, indsamling og bearbejdning af teknologisk og hermed sammenhørende viden, herunder viden vedrørende virksomhedsøkonomi, organisation og ledelse, og formidling heraf til praktisk og kommerciel anvendelse inden for erhvervslivet, den offentlige sektor og samfundet i øvrigt. (Lov om teknologisk service, 1996)
Overordnet set skal GTS-nettet primært varetage to funktioner Vedligeholdelse og udvikling af en basal teknologisk infrastruktur - så virksomhederne har adgang til grundlæggende teknologiske kompetencer, som de ikke selv råder over og som markedet ikke af sig selv ville udbyde. Det handler bl.a. om standardiseringsaktiviteter, adgang til udstyr, prøvning, test, kurser og andre basale teknologiske ydelser. Skabe teknologisk innovation og fornyelse i erhvervslivet - gennem udvikling og spredning af ny teknologisk viden - fx i form af nye metoder, koncepter og ydelser - kan den teknologiske service bidrage til udviklingen af nye videnbaserede produkter, serviceydelselser og processer i virksomheder. (Retningslinjer for Godkendt Teknologisk Service i Danmark 2005)

4. Approach >

4.1. Methodological reflections

4.1.1. Foresight and transdisciplinarity

Modern knowledge production has changed from a classic form (mode-1) characterised by discipline-oriented basic science at universities to a new mode (mode-2) characterised by problem-driven, application-oriented, transdisciplinary science taking place partly outside the universities (Gibbons et al., 1994). This implies that knowledge must emerge from many different 'knowledge dimensions' and be distributed, contextualized and heterogeneous (Gibbons, 1999). Its authority depends on the way in which such collective groups are linked, often in self-organised ways.

As transdisciplinarity and future demands have become important for knowledge production, new challenges have appeared in strategy-making and priority-setting in science and innovation policy. During the last one to two decades, the concept of strategic foresight has become one of the most important tools for priority-setting in science and innovation policy. Typical rationales for foresight exercises have included exploring future opportunities and reorienting science and innovation systems in parallel with building new networks and bringing new actors into the strategic debate (Georghiou and Keenan, 2006). Strategic foresight works systematically with a long-term time perspective and tries to position the different expected developments on a time scale; in practice, the time perspective is often ten, twenty or thirty years, in some cases more.

The European Commission (2002) has provided the following definition: *Foresight can be defined as the application of systematic, participatory, future-intelligence gathering and medium-to-long-term vision-building processes to informing present-day decisions and mobilising joint actions. Foresight brings together key agents of change and various sources of knowledge in order to develop strategic visions and anticipatory intelligence.*

Strategic foresight challenges traditional mono-disciplinary science communities on at least two dimensions. First, foresight exercises include future societal and economic needs and possibilities in priority-setting. Traditional science focuses on 'scientific quality', which is usually measured in terms of innovation of fields, publication rates, citation indexes, etc. Using foresight in priority-setting, the focus is moved from evaluating historical performance to identify future possibilities. Secondly, foresight exercises usually include actors other than scientists in the strategic discussion. In some cases a few industry representatives are included, but usually foresight involves a wider cross-societal discussion of needs, possibilities and priority-settings (Dannemand Andersen and Borup, 2008).

The development of foresight in general follows the lines of the meta-discourse on the appearance of transdisciplinarity science described by Pregernig (2006), which features four elements: interdisciplinarity, participation of stakeholders, problem-orientation and solution-orientation. Transdisciplinarity can be viewed in the way defined by Maasen et al. (2006): *Transdisciplinarity includes interdisciplinarity but goes a step further and transcends the margin* *of science. … First, it transcends science in relation to the persons involved. Transdisciplinarity involves non-scientists in the production and/or evaluation of knowledge. … Second, it transcends science in relation to the problems involved. Transdisciplinarity explicitly orients its knowledge production not only around disciplinary problem-definitions but also around other definitions, derived from pressures, "applications" or from societal stakeholders.*

4.1.2. Expectations

The roles and dynamics of expectations in science and technological innovation are the focus of increasing attention from a wide range of scholars. The scholars seek typically to provide insights in the relationships between expectations and longer-term transitions as well as in the rise and/or fall of various science and technology fields. Expectations can be seen to be fundamentally 'generative', they guide activities, provide structure and legitimation, attract interest and foster investment. Expectations and visions are also important for actor groups beyond scientists and engineers. They play a central role in mobilizing resources both at the macro level, for example in national policy through regulation and research patronage, and at the meso level of sectors and innovation networks, and at the micro-level within engineering and research groups and in the work of the single scientist or engineer. (Borup et al, 2006)

Scientists and researchers are no longer communicating primarily within the borders of their own specific field of expertise, but are typically in contact with many different kinds of actors with a heterogeneity of backgrounds. Firms and policy makers are confronted by large amounts of technology promises (and often also concerns) and have to decide what to do about them. One of the important dynamics often observed in connection with science and technology expectations is 'promises-requirements cycles' in which promises with in the beginning diffuse pictures about possible worlds lead to requirements and identification of more specific functions which can define a protected space and a set of activities (funding and a research project) to follow the promises. Through a number of repeated iterations of such cycles the gab between promises and the technology activities might become smaller (but it is not always the case). Another, to some extent related, dynamics of science and technology expectations is 'hype-disappointment cycles'. This designates the observation in some areas, that expectations, after a period of development and gaining of strength, can break down and more or less suddenly lose the power to drive and coordinate actors. The metaphor of bubbles that get inflated and at some moment burst has been used to describe this. 'Hype-disappointment cycles' have e.g. been of importance in the domain of information and communication technology and in the biotechnology domain. After a period of disappointment the expectations may start to grow again, either with an almost identical content or in a changed and reconstructed form. Successive collapses of expectations can occur within the same area. (Borup and Konrad, 2004).

4.1.3. Classification

One way to establish a basis for a technology foresight study is to classify the system under examination. In a foresight study, one ideally wants a classification of the domain that is at the same time operational, comprehensive and consistent. This implies a classification of the technological domain that delivers an overview of the object under analysis and identifies boundaries. This initial step of the foresight process is essential, because it has a significant impact on the structure of the subsequent steps of the process. In this perspective classification has to be considered, but according to Wyk (1997) most texts on strategy do not offer advice on structured technology classification.

Any classification of a system embodies a dynamic compromise. Each classification system highlights some points of view and silences others. This is not an inherently bad thing, but it is a decision which must be made transparent to third parties. As Bowker & Star say (1999, p. 10-11), "a classification is a spatial, temporal or spatio-temporal segmentation of the world". In an abstract, ideal sense, a classification system will exhibit the following properties: i) there will be consistent, unique classificatory principles in operation; ii) the categories will be mutually exclusive; and iii) the system will be complete. No real-world classification system meets these 'simple' requirements.

4.2. Review

4.2.1. Strategic scanning

The purpose of scanning was to provide an outline of the future need and demand for technological services in Denmark. The concept of technological service is rather broad and is not normally included in foresight studies as a separate topic. For this reason, our approach to the need and demand for technological services is based on generic technological domains and their development trends.

Strategic scanning is concerned with looking ahead. The central questions are, when we scan, what do we look at, and what do we look for? Scanning enhances technology foresight by seeking major distinguishing features in the technological landscape. Strategic scanning thus views the domain in question as an observable totality with clearly identifiable parts (van Wyk, 1999). Foresight studies are either forecasts or prophecies. In a foresight study, viewpoints, attitudes and experiences from a selected group of key agents and sources are collected, prioritized and synthesized in a structured way. Consequently, the outcome of a foresight process reflects the selection of key agents and sources together with the resources available for the entire structuring and synthesis process.

Expectations play a central role in a foresight process, and they may develop in several ways. A key question is where the expectations come from. Looking across published foresight studies, it becomes quite clear that one foresight study is often used as a source of inspiration for the next foresight exercise. This way, expectations may be replicated from one study to another, blurring their origin and perhaps also without them being questioned or challenged.
The technology scanning took the form of scanning selected studies in the open literature. In view of the reflections above, differences and obscure styles in classification principles may introduce difficulties and ambiguities when the various studies are set side by side and compared with respect to content and coverage.

4.2.2. Selection of science and technology foresight studies

The technology scanning was performed by scanning studies in the open literature that were selected to cover both international and national aspects and trends.

Table 1. Reviewed science and technology foresights

Selected foresight study	Year	Motivation
The Eighth Japanese Delphi Survey	2005	The Japanese Delphi Surveys are some of the most comprehensive and thorough technological foresight projects. They have inspired analogous exercises in Germany, France, the UK and other countries.
Key Technologies for Europe	2005	On basis of the Lisbon agenda, the EU Commission (DG Research) performed a mapping of key technologies of strategic importance for Europe within a time horizon of 2015/2020.
UK Foresight: Horizon Scanning Centre	2006	Technology scanning of eight S&T clusters performed as a part of the UK foresight programme.
Finnsight2015	2006	The Finnish foresight study is an example of a comprehensive national foresight study in a country of the same size as Denmark.
European Foresight Monitoring Network.	2007	EFMN issue analysis exploits on an annual basis the outputs of the mapping of foresight exercises.
OECD: Science, Technology and Industry Outlook	2008	The Outlook reviews key trends in science, technology and innovation in OECD countries and a number of major non-member economies.
ForSociety – Multinational Delphi Survey	2007	The Delphi survey is a pilot exercise in a transnational approach in which 15 countries participated.
Danish technology foresight studies	2002-2006	10 Danish technology foresight studies on specific issues.

5.1. The Eighth Japanese Delphi Survey

5.1.1. Overview of analysis

The Japanese Delphi survey is conducted every five years and was first undertaken in 1971. The 8th Delphi survey was conducted in 2004 by the National Institutes of Science and Technology Policy (NISTEP, 2005). The analysis was predicated on a hierarchical structure comprising fields, areas and topics. Areas are positioned between fields and topics, and comprise multiple technologies and research. Topics are key technologies and research topics typical of individual areas. The survey comprises 13 fields, 130 areas and 858 topics (Table 2).

A questionnaire with the participation of about 2300 Japanese experts surveyed scientific and technological, economic and social impacts in each area. The period of prediction for the analysis (the future period looking at) is the 30 years from 2006 through 2035. The survey is intended to provide information useful in examining the next Science and Technology Basic Plan (expected to be the plan for 2006-2010, looking ahead to 2015).

Table 2. Overview of fields and areas – Eighth Japanese Delphi Study, (NISTEP, 2005).

Fields	No. of areas	No. of topics	Areas
Information and communi-cations	9	75	Very large scale information processing; High-productivity computing; Human support (Intellectual support); Ultra-transparent communications/human inter-face; Information security; Information technology for developing social systems; New principles for information and telecommunications; Ubiquitous networking; Software technology for large-scale networks
Electronics	15	69	Integrated systems; Silicon electronics; Optical and photonic devices; Wireless electronics; Bioelectronics; Molecular and organic electronics; Storage; Dis-plays; Energy conversion/storage devices; Digital home appliances; Ubiquitous electronics; Robot electronics; Car electronics; Network electronics; Security electronics
Life science	11	65	Basic research in drug development; Basic research for new medical technolo-gies; Brain generation and growth; Higher-order brain functions; Understanding and treating brain conditions; Regenerative medicine; Monitoring and sensor technology for biological substances; Control of higher-order biological functions; Information biology; Environmental and ecological biology; Nanobiology

Fields	No. of areas	No. of topics	Areas
Health, medical care and welfare	8	80	Personalized medicine; Elucidation of biological defence mechanisms and therapeutic application; Recovery of biological functions focusing on QOL (Quality of Life) and support for it; Application of IT to medicine; Human-centred medicine and construction of healthcare support; Preventive medicine; Measures against emerging and re-emerging infectious diseases; Medicine and welfare for an aging society
Agriculture, forestry, fisheries, and foods	5	46	Elucidation of the complex interaction between biodiversity and ecosystems; Biological solutions to environmental problems and achievement of a sustainable society; Development of production technology that harmonizes with ecosystems and improves the environment; Development of a food system for a safe, peaceful, long-lived, and healthy society and other new technologies for daily life; Elucidation of genome/proteome, and biological information signal transduction mechanisms and development of innovative production technology
Frontier	11	76	Planetary exploration technology; Earthlike life and extrasolar planetary exploration technology; Space and particle research; Basic technology for space transportation and manned space activity; Space utilization technology – basic satellite technology; Technology for high precise observation of Earth environments and for prediction of change; Technology to explore, capture, and cultivate life under extreme environment; Deep Earth observation technology; Ocean and deep ocean floor observation research technology; Space, ocean, and Earth technology for a safe and secure society; Space, ocean, and Earth technology that drives science and technology innovation
Energy and resources	10	51	Innovative nuclear power systems; Nuclear fusion energy; Hydrogen energy systems; Fuel cells; Decentralized energy systems; Renewable energy; Clean-coal technology; Efficient energy conversion and use; Resource assessment; Recycling system (including biomass and waste)
Environment	7	55	Global environment; Urban environment; Focus on identification and mitigation of ecological effects; Environmental economic index; Lifestyle based on environment; Environmental disasters; Water resources
Nanotechnology and materials	10	70	Nanomaterials modeling simulation; Nano measurement and analysis technology; Nano processing, molding, and manufacturing technology; Matter and materials origination, synthesis technology and process technology; New materials from nanolevel structure control; Nano devices and sensors; NEMS technology (nanoelectromechanical systems); Environment and energy materials; Nanobiology; Nanoscience for a safe and secure society

Fields	No. of areas	No. of topics	Areas
Manufacturing	9	59	Manufacturing technology utilizing advanced information technology; Manufacturing technology using virtual design; Manufacturing technology for highvalue added products; Nano-machining/ micromachining technology; Recycling-oriented manufacturing technology with a low environmental load; Human and robot participation in manufacturing; Manufacturing technology in special environments; Advanced manufacturing technology for social infrastructure; Surface modification and interface control technology; Questions regarding other topics
Industrial infrastructure	10	59	Optimization of industrial infrastructure through regional dispersion and concentration; Knowledge management; Corporate decision-making, governance, and management; Public-sector governance and management Risk management and finance; Human resources management; Competition and cooperation in business; Higher productivity in service industries and the service sector; Environmental management; Art, culture, and entertainment that drive industry
Social infrastructure	14	97	Social infrastructure technology for non-densely populated areas; Improvement of structure performance; Revitalization, maintenance, and management of social infrastructure; Social infrastructure technology responsive to an aging society; Environmental technology in social infrastructure; Comprehensive water management technology; Environmental measures appropriate to architectural scale; Security technology as social infrastructure; Disaster prevention technology; Total management of social infrastructure that includes public; New transport system technology; Traffic safety technology; Environmental management in the transport sector; Efficient and environmentally-conscious logistics systems technology
Social technology	11	56	Safety, security, and stability of day to day life; Urban safety, security, and stability; Universal availability of services; Support for the elderly and the disabled; Social application of brain research; Technology for solving international problems; Technology that supports education and learning; Handing down and preserving culture and technology; Know ledge production system; Entertainment technology; Technology assessment

5.1.2. Particular findings

Information and communications fields

Named areas are areas that aim to make technology more advanced and larger in scale, to realize human interfaces that are easy for people to use, to make use more secure, and to utilize information and communications more broadly. In addition, new information and communications principles were named as an area for medium- and long-term research in which the principles are not yet clear. A notable trend was the topics seen as important to be related to protection from perceived threats. These topics included high-security networks, detection of intrusions, and improved safety from natural disasters. This can be seen as reflecting society's current anxiety and social demand for greater safety. The current state of affairs in which anxiety is felt and is important to be relieved cannot be dismissed, but at the same time understanding of the importance of speaking of straightforward dreams, motivating young people, and more forward-looking approaches should be propagated. (NISTEP; 2005, p 93 + 95)

Electronics

Each area was selected with a view to its bottom-up device technology or top-down application. Integrated systems, silicon electronics, optical and photonic devices, wireless electronics, bioelectronics, and molecular and organic electronics belong to the former, while storage, displays, energy conversion/storage devices, digital home appliances, ubiquitous electronics, robot electronics, car electronics, network electronics, and security electronics belong to the latter. The electronics field develops consistently associated with the development of other fields. The electronics field is an exit for the nanotechnology and materials and manufacturing fields, while the information and communications, life science, and environment fields are exits for electronics. The same conditions are expected to prevail 25 years from now as well. (NISTEP, 2005, p139)

Life science

As society ages illnesses that require constant care, such as Alzheimer's disease and Parkinson's disease are expected to become social problems, but in the search for cures, even basic understanding of their mechanisms is insufficient. Brain science research and so on must be further strengthened. In addition, expectations for solutions from life science are high not only for medical care and drug discovery, but also for food and population issues, as well as for food safety, environmental safety, and other issues related to peace of mind. Policy perspectives such as mere industrial and economic vitalization are insufficient, and these issues increasingly must be handled as global problems that extend beyond any single country. In the 21st century, the role of the life science field will be extremely large. (NISTEP, 2005, p187)

Expectations are high for the development of new integrated areas such as nanobiology, regenerative medicine, and monitoring and sensor technology for biological substances and for the creation of new industries based on them. The survey also showed strong long-term expectations for the development of untapped areas such as the environmental and ecological biology, the brain research, and so on. (NISTEP, 2005, p188)

Health, medical care and welfare

Along with understandings of the role of genes as a cause of disease, genetic diagnosis and treatment are becoming more important in healthcare. At the same time, expectations are high for medical transplantation, artificial organs, and regenerative medicine. Genetic treatment and regenerative medicine will likely become the centre of healthcare. In addition, in any age, measures against emerging and reemerging infections cannot be neglected. Firm action must be taken today against AIDS, viral hepatitis, SARS, avian influenza, in-hospital infectious disease, and so on. Prevention of disease, in other words, preventive medicine, will be particularly important in healthcare from now on. The achievement of early detection and treatment of disease through the development of efficient examination systems is also extremely important. Collaboration with other areas on this point is necessary. (NISTEP, 2005, p225)

Agriculture, forestry, fisheries and food

For this survey, an overview was created by selecting the five areas below based on the twin axes of how far the shift of agriculture, forestry, and fisheries technology that is inseparable from issues such as population and the environment in 21st century technological innovation will advance in the context of science and technology, and how society will form new conceptual frameworks, (NISTEP, 2005, p226)

- Elucidation of the complex interaction between biodiversity and ecosystems
- Biological solutions to environmental problems and achievement of a sustainable society
- Development of production technology that harmonizes with ecosystems and improves the environment
- Development of a food system for a safe, peaceful, long-lived, and healthy society and other new technologies for daily life
- Elucidation of genome/proteome, and biological information signal transduction mechanisms and development of innovative production technology

Frontier

The fields of energy and resources, environment, information and communications, life science, social technology, and nanotechnology and materials all receive high support, with slight variation, as fields with which the frontier field should seek to integrate and collaborate into the future. This reflects and suggests that the frontier field is formed by integrating the elemental technologies of other science and technology fields and plays a leadership role by providing a foundation for the perspective of modern outlooks on the universe and the Earth, thus giving other fields a strategic basis for development. (NISTEP, 2005, p291)

The highest expectations are for the areas of space, ocean, and Earth technology for a safe and secure society; technology for high precise observation of Earth environments and for prediction of change; and space, ocean, and Earth technology that drives science and technology innovation. (NISTEP, 2005, p291)

Energy and resources

Comparing areas, expectations are high for hydrogen energy systems, fuel cells, and efficient energy conversion and use, followed by recycling systems (including biomass and waste). Expectations for decentralized energy systems, clean-coal technology, and renewable energy are moderate, while those for innovative nuclear power systems, nuclear fusion energy, and resource assessment are relatively low. (NISTEP, 2005, p335)
Looking at the technological topics, technology for geologic disposal of high-level radioactive waste received the highest degree of importance, with recycling systems, gasification power generation and synthetic fuels manufacturing, fuel cells, hydrogen supply infrastructure, and CO2 separation and storage also receiving high scores. The group with a high degree of expertise assigned fast breeder reactor (FBR) systems, energy management technology, and efficient large combined cycle power generation a high degree of importance, but the average assessment was relatively low. (NISTEP, 2005, p335)

Environment

In conclusion, this Delphi method questionnaire itself covers a very extensive array of questions and responses, and it is nearly impossible to analyze them in detail. In general, however, it strongly reflects today's Japan. The importance of environmental issues in Japan, particularly those related to the effects of the environment on the human body, is declining because of progress in improving the environment. Instead, we have reached a point when a shared awareness that it is necessary to judge importance based on contribution to global environmental improvement, is essential. (NISTEP, 2005, p371)

Nanotechnology and materials

Policy proposals from the particulars of the area can be summarized as follows. (NISTEP, 2005, p403)

- Nanomaterials modeling simulation → human resources development
- Nano measurement and analysis technology → investment of human resources and funding in basic technology will be effective
- Nano processing, molding, and manufacturing technology → support for intellectual property rights, promotion of research exchange, and support for small and medium businesses
- Matter and materials origination, synthesis technology and process technology → collaboration and cooperation among multiple organizations
- New materials from nanolevel structure control → research to develop practical applications is essential
- Nano devices and sensors → university-centered research systems integrating industry
- NEMS technology → establishment of a joint-use center
- Environment and energy materials → advancement through effective use of nanomaterials
- Nanobiology → frameworks for organic collaboration among researchers
- Nanoscience for a safe and secure society → human resources development and accomplishment of international harmonization of relevant policies

Manufacturing

First, the largest expected impacts either currently or in the medium term (2015–2025) are the contributions of "nano-machining/ micromachining technology" to increased intellectual assets and to the creation of new industries or businesses and the contribution of "recycling-oriented manufacturing technology with a low environmental load" to safe and secure society. In addition to the two areas above, medium-term expectations are high for areas such as "human and robot participation in manufacturing." The largest increase in expectations from the current time to the medium term is in "manufacturing technology in special environments" such as zero gravity environment. Fields with which manufacturing technology should collaborate over the coming 5 to 10 years are first, "information and communications" and second, "nanotechnology and materials." Underlying this is the extreme importance of their relationships with the manufacturing field. (NISTEP, 2005, p442)

Industrial infrastructure

Proper form of promotion measures for this kind of technology are (NISTEP, 2005, p479):

- First, government-led funding supply and the introduction of special projects are insufficient to realize these industrial infrastructure technologies. More refined promotion measures are necessary. Methods that are based on consideration of the individual conditions of the entities developing and utilizing the technologies, which are inseparable from corporations, government, and social systems, and that are coordinated by the relevant entities are necessary.
- Second, government or political leadership is still essential. Government leadership is vital to regional decentralization of industrial infrastructure, corporate governance, education, technology policy, and so on. In public-sector management, it is the action of government itself that is at issue.
- Third is the importance of human resources development. In particular, advanced training at the university and graduate school level of human resources who can develop and disseminate such technologies is vital. At the same time, however, the division between science and humanities education forms a barrier, and a proper form of education to integrate them is necessary. As measures towards this end, the fusion of science and the humanities education at the department level and the implementation of multiple majors and degrees at the graduate school level are important.
- Fourth, the proper form of research and development funding is an issue. Direct distribution of research funding alone is insufficient. The question is how to form a system in Japan that can distinguish between early-stage and middle-stage corporate technical development and effectively allocate funds.

Social infrastructure

The strong realist tendencies and, in a sense, strong conservative tendencies of the respondents are reflected in these survey results. In fact, topics with high scores on the degree of importance index are concentrated in the areas "disaster prevention technology" and "revitalization, maintenance, and management of social infrastructure," perhaps reflecting the frequent occurrence of natural disasters in recent years. In addition, predicted times of both technological realization and social application for field topics tend to be markedly on the early side relative to all topics. The results for the fields with which the social infrastructure field should integrate and collaborate, the environment, social technology, and information and communications fields, were also very much in line with common sense. (NISTEP, 2005, p515)

Social technology

The common thread of these social technologies is that they are technologies to respond to social needs and they require the integration of knowledge from multiple specialized areas in order to address problems. In many cases, the necessary specialized areas are in both the natural sciences and the social sciences or humanities. (NISTEP, 2005, p567)

This analysis investigated expected current and medium-term impacts for each area. For social impacts related to safety and security and to social vitality, the 4 areas in the field with the highest scores are 'urban safety, security, and stability', 'support for the elderly and the disabled', 'safety, security, and stability of day to day life' and 'universal availability of services'. The areas receiving the lowest scores were 'entertainment technology', 'handing down and preserving culture and technology' and 'knowledge production system', but these received relatively high scores on increased intellectual assets. (NISTEP, 2005, p567)

5.2. Key technologies for Europe

The High Level Group on Key Technologies was set up by the unit K2 "Science and Technology Foresight" of DG Research from the European Commission in December 2004 (EU, 2005). The mission was:

- to assess the potential and the emerging scientific and technological research topics in fifteen specific areas, their impact on EU competitiveness and societal fabric, and the potential response of EU and its Member States
- to examine what possibilities exist for a uniquely European approach to exploiting the potential synergies across these technologies, and develop guidance for new research agendas
- the findings of the group are to assist with the identification of possible priorities for the European Research Policy

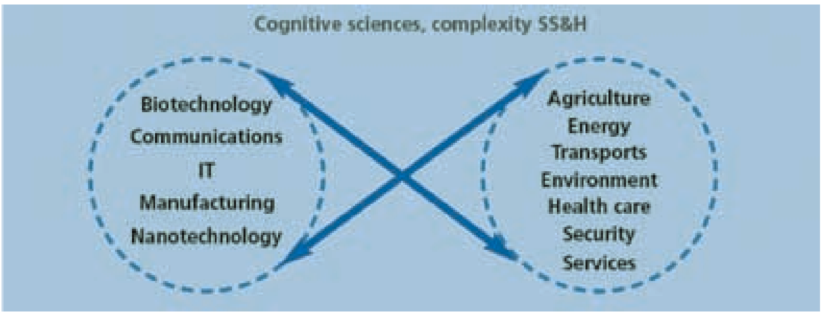
The fifteen specific research and technology fields are: Agriculture; Biotechnology; Cognitive sciences;
Communications; Complexity; Energy; Environment; Health care; Information technology; Manufacturing;
Nanotechnology; Security; Services; Social sciences and humanities; Transport.
For each sector there was an expert whose task it was to produce a report which was subsequently validated by other experts in the field.

5.2.1. The cluster approach

The Key Technologies were grouped in three clusters of sectors with similar characteristics (Figure 2):

- *Socio and systemic approaches:* cognitive sciences, complexity and SS&H (Social sciences and humanities). This cluster can propose a theoretical framework for the systemic and holistic models required to study the inter-action within its members, the horizontal technologies, the societal challenges as stand alones and also, very importantly all the simultaneous interactions intra and inter clusters.
- *Transversal technologies:* biotechnology, communications, IT, nanotechnology and manufacturing. This cluster groups the technology intensive sectors, which per se, in conjunction with others, or converging with others provide the technological base for the sectors that target the societal challenges.
- *Targeting societal challenges*: agriculture, energy, environment, health care, security, services and transports. This cluster includes the areas that deal with the main socio-economic concerns of EU citizens. These areas need to feed on their specific knowledge, use the potential provided by technology, the systemic and holistic approaches and the social models to address the challenges that each one faces.

Figure 2. Key Technologies - Cluster Approach (EU, 2005. p20)



5.2.2. Main findings and key issues – Socio and systemic approaches

The Social Sciences and the Humanities (SS&H) (Gaskell, 2005)

The SS&H are a meta-category covering a broad canvas including philosophy and history, the single social scientific disciplines of economics, sociology, political science, anthropology and social psychology, related disciplines such as statistics, demography, socio-legal studies and social policy; and a variety of trans-disciplinary subject areas such as communication and information technologies, health, environment, development, and science and technology studies. While they might be described as unified in the sense of a more of less common objective of the scientific study of society, they differ in their typical research questions, theoretical approaches, levels of analysis and methodological approaches.

Without question, scientific and technological innovation will make an instrumental contribution to the Lisbon goals. However, science and technology alone, will not deliver the Lisbon objectives. While science and technology opens up options for the future, showing what can be achieved, it does not tell us what should be achieved or how it should be achieved. These are questions for society. Thus, the Lisbon agenda is a call for a joint effort on the part of the 'hard' and 'soft' sciences to contribute to the realisation of Europe's future. The inclusion of the SS&H in the category of 'key technologies' is in recognition of this reality.

In particular the following key issues for research in the SS&H are identified: Economic performance/Socio-economic sustainability; Democracy, governance, citizenship; European culture/Multi-culturalism and diversity; Science, Technology & Innovation/Science and society; Welfare and welfare sustainability; International migration and ethnicity; Racism, xenophobia, discrimination; Ethics and human rights; Environment and sustainability; Societal regulation and development; Security.

Complexity (Priami, 2005)

All the disciplines are facing a scaling up of the size of the problems they must cope with which is not supported by a corresponding enhancement of the frameworks and techniques of the applicative domain in hand. The complexity of the processes we want to model and control is mainly given by the interaction of the constituents of the systems and the consequently emergent behaviour.

Many disciplines need a comprehensive approach to enhance their knowledge and scale up their results. Examples are: Systems biology; Humane genome project; Programs and computation; Synthetic biology; Complexity in economics.

Complexity and systemics can be handled with the combined action of the following strategies:

a. Definition of suitable abstractions that allows researchers to concentrate on the important aspects of the problem in hand with respect to the kind of investigation under development;
b. Introduction of new ICT frameworks to model, analyze, simulate and control the complex system we are interested in.
c. Revisiting the models and frameworks used s o far in different disciplines to cope with large-scale systems and unify them in a science of complexity.
d. Definition of interdisciplinary curricula oriented to complex systems study to create the critical mass of skilled people to push the field.
e. Re-definition of the parameters for recruitment of scientists to favour the interdisciplinary activities.

Cognitive science (Andler, 2005)

Cognitive science is the interdisciplinary study of mind and brain, combining the concepts, methods and insights of large parts of psychology, neuroscience, evolutionary biology, linguistics, philosophy, anthropology and other social sciences, and formal methods from computer science, mathematics and physics.

The potential for applications, in the medical and psychiatric realm, for sensory and motor prostheses, for normal, remedial, and compensatory education, for cognitive, communicative, and decision-making tools is enormous. The impact on individual, social, and cultural practices and self-understanding, with implications in the political, economic, and ethical realms, cannot be underestimated. Finally, the stimulation which cognitive science brings to its core contributing disciplines, and to the general movement of scientific and cultural ideas, is considerable.

Cognitive science is undoubtedly the most ambitious scientific enterprise of the XXIth century. Its agenda is that of psychology. However, it is not simply psychology. It is psychology pursued by novel means, with contributions of disciplines which are also centrally concerned with the mind, and carry with them a set of methodologies which taken together have made it possible to overcome some of the drastic limitations of the traditional programmes in scientific psychology. While psychology has long ceased to be a unified field, cognitive science, by considerably broadening the toolboxes of previous paradigms of scientific psychology, has transformed its ill-formed initial ambitions into a sheaf of connected research programmes, conceptually well-founded, and covering not only the traditional topics of memory, problem-solving, categorisation and the like, but also emotions, social cognition, linguistic competence, perception, action, selfhood, consciousness, etc. The result is that, in contrast with past eras in psychology, knowledge acquired in cognitive science can be exploited and enriched by a whole range of pure and technological disciplines, ranging from computer science, to health science, human and social science, education, law and government, industrial processes, trade, etc.

5.2.3. Main findings – Transversal technologies

Biotechnology (Saviotti, 2005)

During the Human Genome Project one had often the impression that the final objective of biology was within sight. By mapping the human genome the HG project showed clearly that in very few cases the expression of proteins by genes was due uniquely to the nature of the gene. The environmental conditions under which protein expression takes place are equally important. This growing awareness has given rise to a post-genomics era, in which specialities like functional genomics, proteomics etc. emerge. Thus, we are witnessing a process of differentiation and specialisation in biotechnology. This process has at least three components: one consisting of the internal differentiation of the discipline, another one due to the specialisation by target application, and a third one due to the emergence of new disciplines from the merger of previously separate ones. An example of the second component in the health field would be specialisation by disease. An example of the third component would be the emergence of bioinformatics from the merger of biology and information technology.

It is possible to classify biotechnology applications into three fields, red or health related, green or agriculture related, and white or industrial biotechnology.

- **Health**: The present industrial structure constituted by large diversified firms and dedicated biotech firms collaborating to create new drugs can be expected to survive over the next ten-fifteen years, possibly with some modifications. The trend towards an increasing differentiation continuously creates new niches in which for a while dedicated biotech firms have a comparative advantage.
- **Agriculture:** The development of new GM plant varieties is going to require some time. For the foreseeable future most cultivated plant varieties will be obtained by means of traditional breeding techniques. The simultaneous cultivation of GM and of traditional plant varieties will survive not only due to the time and resources required to develop a sufficiently wide range of GM plants with useful traits, but to the need to give citizens choice.
- **Industrial:** So far the impact of biotechnology has been concentrated on the pharmaceutical sector, with agriculture coming a distant second. This is likely to change in the next ten to fifteen years as a consequence of a number of factors. The combination of rising energy prices and of a growing need to reduce the environmental impact of all technologies can be expected to induce a considerable amount of R&D aimed at replacing fossil fuels and non renewable inputs with renewable biological ones. In some cases even physical equipment will be replaced by biological organisms, such as bacteria or yeasts. The scope of industrial biotechnology is extremely wide, to the extent that it can be described as a bio-economy, an economy in which non biological processes will be replaced by biological ones.

Communications (Kavassalis, 2005)

During the last years, digital networks have become a critical component for new business and social functionalities that would be totally impossible to be obtained otherwise. Communication technologies have migrated from the laboratories and the head offices of the telecom operators to a ubiquitous presence in production and exchange processes, delivery channels and, virtually, in any organizational structure that shape modern economic and social life. In brief, communications infrastructures will become ever more complex and need to be more efficient by incorporating these new branches in a totally seamless way. Innovating through new networking ideas that realize the potential of the "converging technologies" allow also for the emergence of effective information economies and other virtual structures supporting communities and individual social and professional lives.

Key long-term research areas recommended are: 1) Enabling infrastructure technologies and technologies for security, 2) Applications (focusing on real time and organization-wide applications), 3) Network design and novel architectures for the Internet, 4) Models for understanding the networks of today and tomorrow, 5) Cyberinfrastructure, digital networks and information economies, 6) The triangle Internet, Mobile, Wireless (or beyond "beyond-3G").

Information technology (Bibel, 2005)

Two general visions are considered most important. One, in accordance with the first characteristic, is the integration of intelligent systems within the natural, human, but also technical sphere. This is why AI, virtual reality, (multimodal) Human/Computer Interface (HCI), humanoid robotics and, generally, the coupling and reconciliation of the real with the virtual are considered top issues for R&D in the coming years. This vision is about to transform virtually every other domain (S&T, engineering, design, development, and production, business, government and administration, and many more discussed in detail). The other vision is the transformation of software production into a scientific discipline, incorporating also new computational paradigms and leading to a high degree of automation as well as to an increasing autonomy, robustness and tolerance of systems.

In view of these two visions the report proposes four major challenge problems: the Automation of Programming based on descriptively specified system and environment models; the development of humanoid robots on the basis of bionic and CogSci principles; the development of an Integrated Hybrid Public Transportation System and of a Semantic Law Support System.

Manufacturing (Sá da Costa, 2005)

The seven challenges that lie at the heart of the near future of manufacturing in this increasingly complex and globalize environment are: increasingly competitive global economic climate; anticipate new market and societal needs; rapid advances in science and technology; increase supply chain efficiency; environmental challenges and sustainability requirements; integrate new knowledge and improve workforce skills; and, societal values and public acceptance of technology. These challenges will influence research trends in manufacturing over the next 10 to 15 years.

To attain this challenges manufacturing enterprises have to progress towards: customer responsive enterprises, totally connected, reconfigurable and efficient, based on knowledge and technology innovation and, environmental sustainability. Many of manufacturing research needed to attain these challenges are crosscutting areas, that is, they are applicable to several enabling technologies. It is wise to establish an interdisciplinary manufacturing research and development program that emphasizes multi investigator consortia both within institutions and across institutional boundaries; to focus long-term manufacturing research on developing capabilities in the enabling technologies to meet the challenges, with an emphasis on crosscutting technologies. Adaptable and reconfigurable manufacturing systems, information and communication technologies, and modelling and simulation are three key enabling technologies research areas that address several manufacturing challenges. Two important breakthrough technologies - submicron manufacturing and enterprise simulation and modelling - will accelerate progress in addressing the manufacturing challenges.

Nanotechnology (Saxl, 2005)

Nanotechnology and future socio-economic challenges

- **Energy:** Bio-inspired, lightweight, efficient solar power collectors; flexible, lightweight, interactive displays for virtual meetings, conferences and even holidays / virtual newspapers; nano composites for energy efficient vehicles / engines; fuel cells; energy efficient, resource-saving building materials / lighting / glazing; 'clever', lightweight packaging; nano-enabled, local manufacturing (bottom-up manufacturing at point-of-use).
- **Water:** Self-calibrating nanosensors; point-of-sample, high-speed analytical techniques for measuring water quality; nano-based, filtration and purification techniques, using membranes systems. Stay-clean clothes / less water intensive manufacturing / food production.
- **Environment:** Self-calibrating, cheap, fast air and water pollution sensors that can detect a wide variety of organic and inorganic chemical species. Novel catalysts for extracting harmful exhaust chemicals from cars, aircraft and power stations.
- **Waste:** Recyclable, minimalist 'smart' packaging that uses less resources but offers more attributes; able to monitor and identify contents, provide data on energy to produce and transport, and signals its location at any time. Important in the reduction of waste food. More for less – nano-enabled products require less energy and materials to produce.
- **Healthcare / Ageing population / Diseases of the Less Developed World:** Remote health monitoring / non-invasive diagnosis; fast analysis of genetic predispositions to illness leading to genome-based therapeutics. Nano-based imaging and drug targeting and delivery for early identification and minimally toxic treatment of disease. Regenerative medicine. Drug / hormone delivery on a needs-basis using electronics-derived technology. Patient-friendly, 'smart' cochlear and retinal implants. Medical textiles, with health monitoring, transmission of information and therapeutic capabilities; nanostructured bandages that encourage cell growth; infection reduction, through anti-bacterial dressings, surfaces and textiles. Nano-enabled technologies for quality of life for the elderly or infirm (lightweight, flexible interactive displays / robot 'helpers') activated verbally, by minimal movement or even thought. Affordable diagnostics and treatments for the killers such as HIV Aids, TB and malaria.
- **Food:** Less wasteful, feature-rich packaging, (able to detect pesticides, deterioration, inform on provenance etc); antibacterial packaging and food preparation surfaces e.g. using nanoparticulate silver.
- **Animal Welfare:** Advanced computer-based modelling of nanoparticle behaviour in living systems and the environment to eliminating animal-based testing; cell-based toxicological and efficacy tests for new drugs and nanoparticles (more relevant than animal-based testing) leading to the use of the patient's own cells - the 'personalised medicine' revolution.
- **Agriculture:** Nanosensors for monitoring soil health.
- **Lifestyle:** Nanomaterials for flexible, cheap, low power, paper-like displays for creating virtual environments, providing free ubiquitous access to information, entertainment, education; on textiles, domestic goods. Inclusive.

5.2.4. Main findings – Targeting societal challenges

Agri-Food industries and Rural Economies (Downey, 2005)

In response to the ongoing reform of the Common Agricultural Policy, EU enlargement and more liberal world trade in agricultural products, allied to increasing society/consumer demands, as well as other policy developments and international drivers of change, Europe's agri-food industries and rural regions will be radically transformed in the coming decade. Following the fundamental reform of the Common Agricultural Policy, the overall policy framework has shifted towards rural development, involving: a) the development of an internationally competitive multifunctional European agriculture, producing market-required food products and environmental goods and services, b) the diversification of the economies of rural regions throughout the enlarged EU, and c) the protection and management of Europe's rich heritage of rural landscapes and cultural diversity

As sectors inherently based on the exploitation of natural resources, Europe's agrifood industries are confronted with virtually unique challenges by the two overarching EU goals of Competitiveness and Sustainability. Countries that achieve the optimum balance between the economic dictates of profitability in agriculture, and at the same time address environmental and consumer concerns will have internationally competitive agri-food industries in the coming decades. EU agriculture and rural regions must be repositioned in the knowledge economy, by developing knowledge-based multifunctional agri-food industries and rural economies.

Energy (Jørgensen, 2005)

End-use technologies and energy efficiency. Industry: new and profitable products, process integration, heat recovery, cogeneration, efficient use of raw materials, recycling, new electro-technologies, reducing environmental impact of both production processes and product use. Buildings: advanced insulation technologies, advanced windows technologies, building materials using recyclable materials, thermal storage materials, heat pumps, micro CHP, alternative refrigeration, low-power pulps, hybrid lighten systems, advanced sensors, integrated control networks. Transport: alternative fuels to gas and diesel.

Biomass, biogas and biofuels. Europe has become a market leader in electricity generation using biomass in conventional steam cycle power plants. New science and technology opportunities could be pursued in biofuels made from the cost-competitive cellulosic raw materials. New opportunities for the European biomass industry lie within the development of new and more efficient technologies and processes for producing liquid biofuels and in designing new plants optimised for energy use, balancing tradeoffs between high yield, fertiliser requirements and environmental impacts.

Hydrogen and fuel cells. Hydrogen technologies comprise: a) production technologies (conversion of hydrocarbons, electrolysis of water, direct water-splitting technologies), b) stationary and mobile storage technologies (compressed hydrogen, storage by adsorption), and c) end-use technologies (fuel cells).

Photovoltaic technologies. The Si-crystalline cells are a mature technology and will dominate the PV applications for the next decades. Thin-film silicon cells could be a solution in case of silicon scarcity and could be used in grid-connected applications. Compound semiconductor cells are very expensive, but could find niche applications as PV concentrating systems. Dye-sensitised cells show instability but could find niche applications such as PV windows, solar home systems etc. Polymer solar cells are still inefficient and unstable, but could be used in buildings.

Clean fossil fuels. Scientific opportunities relate to efficiency improvement of well-known technologies as well as cleaner technologies and CO2 capture and storage. This includes a stronger effort within advanced pulverised fuel combustion, circulating fluidised bed and the development of commercial intensified gasification combined cycle and pressurised fluidised bed combustion power plants.

Nuclear fission. Four critical points should be addressed: cost, safety, waste and proliferation.

Nuclear fusion. Fusion is a long-term technology, and the time frame for large-scale commercially viable fusion energy is 30-50 years.

Healthcare (Braun, 2005)

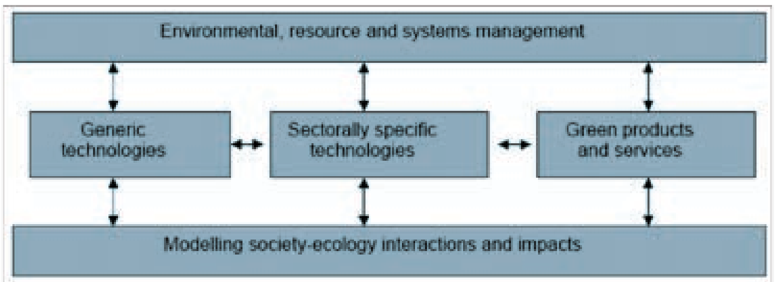
An increasing convergence of nano-technology biotechnology, information technology and cognition science is expected, with huge application opportunities in the health sector. Technological advances with particular application opportunities in the healthcare sector (particularly for diagnosis and treatment) have been identified in the following areas: pharmacogenomics; gene therapy; genetic diagnostics; stem cells; telecare, telemedicine and ehealth; bioinformatics; minimally invasive surgery; medicinal nanotechnology applications; regenerative medicine; artificial and bioartificial organs; tissue engineering; rational drug design; xenotransplantation. Modern healthcare technologies and prevention strategies will have the potential to extend the life expectancy of people, to increase their quality of life, to open up new tools for health prevention, monitoring, diagnosis, treatment and aftercare in an ageing European society. Promising developments over the next few years are expected to include vaccines against infectious diseases; the ability to predict, delay, prevent and even cure cancer, heart disease, and certain neurological diseases; genetic engineering (e.g. the human genome project), continuing developments in biomaterials for prostheses and advances in robotics.

Environment (Weber, 2005)

Environmental Technologies cover a broad spectrum of technological development. In the past, Environmental Technologies were mainly associated with individual sectors, but increasingly emerging generic technologies are being recognised as crucial (biotech, nanotechnology, materials, ICT). In addition, cross-cutting developments like new environmentally oriented product-services and environmental and resource management are likely to grow further in importance. A fundamental change must also be seen in the shift in perspective from environmental impact analysis to the analysis of ecology-society interactions, where system boundaries for assessing environmental impacts are drawn more widely and lead to different conclusions. The key long-term challenge for the future consists of realising system innovations, i.e. combinations of radical technological and organisational/social innovations in many areas of economic activity, that allow reconciling economic, social and environmental objectives. On the way to realising system innovation, however, the requirements of competitiveness need to be met.

Environmental Innovations have changed in terms of basic approach over the past years. One can certainly distinguish three main phases: End-of-pipe technologies or system optimisation (70ies to 80ies); Process-integrated technologies or system redesign (80ies to 90ies); System or functional innovations (late 90ies to present). The key issue for the future is thus how to move beyond system optimization and system redesign towards system or functional innovations. For that purpose, specific Environmental Technologies will have to be embedded in broader transformation strategies. As sketched in the figure there are five main areas of environmental technology research for the future: environmental system management and policy, generic technologies, sectorally specific technologies, green products and services, and the modelling of society-ecology interactions.

Figure 3. Key areas of research on Environmental Technologies.



Security (Sieber, 2005)

The comité Européen de normalisation, technical board/Working group 161- CEN BT/WG 161 on ‘Protection and Security of the citizen’ adopted the following definition in January 2005: “Security is the condition (perceived or confirmed) of an individual, a community, an organization, a societal institution, a state, and their assets (such as goods, infrastructure), to be protected against danger or threats such as criminal activity, terrorism or other deliberate or hostile acts, disasters (natural and man-made)”.

The underlying structure to this definition is a framework in which aspects of security is classified in three dimensions: 1) targets (e.g. resources, infrastructures, ICT, transportation, public health, industrial base, government, people), 2) threats (e.g. explosives, chemical agents, biological agents, cyber, conventional weapons, radiological/nuclear materials, ordinary physical objects used for attacks, human beings, natural disasters), 3) countermeasures (e.g. assessment, protection, detection, identification, response, mitigation, restoration, management).

Although advances in individual technologies are very much needed, modern security missions and civil crisis management require urgently a strong focus on integrated concepts. It is suggested to follow and develop the concept of network enabling capabilities (NEC) which are much more concerned with evolving capability by bringing together decision-makers, sensors and other equipment/ systems, and enabling them to pool their information by 'networking' in order to achieve an enhanced capability. In NEC, the key word is interoperability and this at the level of respectively services (human interoperability), systems (technical interoperability) and information (data interoperability). Converging technologies are a key area to be explored.

Services (Ganz, 2005)

There is little knowledge about how to develop, design and model service driven innovation processes systematically. A better understanding of the interrelationship of service and innovation processes could lead to sustainable enforcement of international competitiveness.

The rapid growth of service is an indication of fundamental changes in the production and consumption structures of our societies. The rapid integration of European economies requires new answers from a European oriented service research. Europe has to recombine the cultural diversity, the existing know-how and the different economic strengths of the single member states. Within this process the development of services plays a vital role. With the implementation of a common domestic market for services, the attention shifts to the process-related dimension of economic transactions.

Service research topics: a) **Basic research topic**s: Definitions, typologies and morphologies of services. Models and systems of services. Specification of standards of services; b) **Applied research topics**: Service innovation. Service management. Benchmarking and assessment, c) **Megatrends**: Internationalisation of the service economy. Professionalisation of the service economy. Quality of service employment, and d) **Growth sectors**: Business services. Educational services. Financial services. Information services. Media and telecommunication services. Non-professional services. Public services. Services in manufacturing industries. Social and health services.

Transport (Theys, 2005)

The key technologies for the future of transport cannot be envisaged as a simple continuation of past dynamics. They must also take into account the eventuality of discontinuities and shifts in the next 30 years, in particular, linked to the change in mobility spaces, to the massive integration of new Information Technologies into the market and the competition faced from Asia and above all the risks related to climate change and petrol shortage. Faced by the eventuality that in 2030 transport will on its own consume the available petrol sources, it is not sufficient to develop incremental technologies as we did over the previous decades but also to conceive voluntary transition strategies to adopt rupture technologies.

Based on the results of the technology platforms and the prospective analysis of the trends and key challenges of the 2030 horizon, this report proposes within a dual perspective of continuity and rupture, a coherent list of 25 key technologies for the future of transport: 1) fuel cells and use of hydrogen, 2) advanced systems of storage of energy, 3) biofuel of second generation, 4) hybrid motorization, 5) new materials and lightening of vehicles, 6) techniques of recycling and dismantling of vehicles and their components, 7) new catalysts and advanced systems of treatment of pollutants, 8) techniques of attenuation and 'masking' of noise, 9) new electric and electronic architectures, 10) electromagnetic compatibility of equipment and signals, 11) new techniques of identification, positioning, monitoring and navigation of vehicles, 12) new IT and communication technologies, and RFID techniques for optimising 'logistic chains', 13) interworking and optimisation of railway network, 14) advanced systems of navigation and monitoring of air traffic, 15) systems of driving assistance and ergonomics of man-machine interfaces, 16) techniques of interface between modes or 'multimode', 17) reliability and impact strength of complex systems of transport vis-a-vis risks of vulnerability and crisis, 18) development of intelligent sensors and their application to self-diagnosis and auto-reparation of vehicles, 19) trains of the future, 20) new concepts and paradigms for air transport, 21) new motorizations and new concepts for complex ships, 22) design and the marketing of specifically urban vehicles, 23) design of vehicles and systems of transport accessible to people with reduced mobility, 24) truck of the future, 25) new techniques of design and production for a manufacturing that is less expensive and more flexible.

5.3. UK Foresight – Horizon Scanning Centre

In its Science and Innovation Investment Framework 2004-2014, the British Government committed to establishing a Centre of Excellence in Horizon Scanning, to be based in the Foresight directorate of the Government Office for Science. The office has described 8 clusters of emerging science and technologies (Office of Science and Innovation, 2006). The clusters are not forecasts or predictions, nor are they statements of policy preference. Each cluster paper describes the constituent technologies and provides information on trends, potential barriers and enablers. These clusters have the potential, either as enhancers or disruptors, to: transform the delivery of public services; challenge society; and/or affect wealth creation over the period to approximately 2015 - 2020.

Table 3. UK Foresight Horizon Scanning – technology clusters.

Technology cluster	Constituent technologies and areas of science
Advanced materials and robotics	Modelling, characterization and instrumentation Electronic polymers Intelligent polymers for biomedical and other uses Smart materials that react to the environment Carbon nanotubes and lighter vehicles Thin-films coatings Bio-compatible and bio-mimetic materials leading to bio-mechanical hybrids Robotics Manufacturing & fabrication processes, including manufacturing with light Materials for sustainable production and consumption Active packaging Smart and interactive textiles
Body and mind sciences	Neurosciences and imaging In-situ diagnostics Imaging and pathology Social science, behavioural science, genetics and mathematical modeling Nucleic acid technologies Stem cells and tissue engineering Performance enhancers Bio-computing interactions Microfluidics Proteomics
Energy technologies	Carbon capture and storage Nuclear fission Micro-generation Biomass Advanced battery technology Use of hydrogen Fuel Cells Enhanced oil recovery
Information handling and knowledge manage-ment	Bandwidth and capacity Geography and sensing Interfaces and representation Searching and decision-making Simulation and modeling Robustness and identity management

Technology cluster	Constituent technologies and areas of science
Nanotechnologies	Nanomaterials Nanometrology Bio-nanotechnology and nanomedicine
Network interactions	Intelligent sensor networks Mobile Ad-hoc NETwork (MANET) Social network analysis; mapping of different entities (people, organisations etc.) Enterprise integration technology Digital-to-physical environment integrators (and vice versa) SWARM technology. Swarm Intelligence Military network
Security	Biometrics and new means of identifying individuals Complex systems and systems integration Pervasive computing, imaging, modelling and simulation, incl. human behaviour Information handling and knowledge management Surveillance Sensors for detection, controlling, monitoring and tracking dangerous materials. Terahertz, CCTV and other remote sensing technologies Millimetric radar for the detection of objects at high resolution Software – pattern recognition, emergent behaviour, risk identification, etc. Game theory
Sensors and tracking	Radio Frequency Identification and sensors Pattern recognition and data mining Secure identification

5.4. FinnSight 2015

FinnSight 2015 - Science and Technology in Finland in the 2010s, is a joint foresight project of the Academy of Finland and Tekes, the Finnish Funding Agency for Technology and Innovation. The project was carried out in 2005-2006. The foresight project examined the change factors that have impact on Finnish business and industry and on Finnish society, identified future challenges of innovation and research activity and analysed such areas of expertise which will foster the well-being in society and the competitiveness of business and industry by means of scientific research and innovation activities. The focus in foresight was on social and global issues. (Academy of Finland & Tekes, 2006)

The foresight project highlighted the following driving forces:

- **Globalisation is redistributing roles.** There are two prominent driving forces in today's global operating environment. The first is the trend of increasing mobility: the flow of goods, money, capital, people, ideas, cultures and values across national boundaries is continuing to expand. The second is the growing interdependence of different parts of the world, their increasing interaction and cooperation in the economy, production, social development, communications and human exchange.

- **Changes in the population structure are shaping the economy.** In almost all advanced countries population growth is slow, and the proportion of older people is set to rise very rapidly in the 2010s. These countries will need more staff in the service sector as well as in jobs requiring high levels of education. Population ageing is significantly changing the structure of consumption. In particular, the demand for health and care services is soaring.
- **Information is everywhere**. Digital information and networks are paving the way to ubiquitous networking. Government functions and services are increasingly moving to web-based networks, which means they are accessible to all people at all times and in all places. There is increasing convergence of telecommunications networks and computers. Technological convergence also enables completely new ways in which people can link up to networks both technologically, professionally and socially. This complex web of networks offers greater scope for a new kind of creativity. Based on the principles of openness and sharing, the open source concept is continuing to gain in popularity.
- **Sustainable development: a safe option for the longer term.** As well as being ecologically sustainable, our decisions and solutions have to be economically viable, socially just and culturally valuable. Investment in competence on sustainable development is a safe option in the longer term, but it is not clear how and by what means such development can be achieved, and those means are certainly not always profitable in the short term. The world's ecosystems are in a state of accelerating change as a direct result of human activity, but we continue to know too little about those changes. The world water problem is getting progressively worse. The lack of clean drinking water and waste management problems call for urgent solutions in many parts of the world. Organisations and their management and leadership are becoming increasingly complex. People who are working full-time in production in advanced countries will be spending more time than before in training and education.
- **Open source concept set to expand**. Work is becoming increasingly independent of time and location. More partnerships and cooperation means more communication. This open innovation concept will continue to grow and expand with the rapid changes in earning models. Increasing ubiquity is making the distinction between work and leisure increasingly blurred. The key workforce groups are ever more pressed for time and also have increasing purchasing power. Care professionals and service providers are one of the biggest groups of experts. Where knowledge workers operate globally, services are needed locally.
- **Equality in cultur al encounters.** With the advance of globalisation, different sets of values are coming into contact with one another more and more often. As the need for competent people continues to increase with population ageing, positive multiculturalism combined with the welfare state is definitely a competitive asset. Young people in particular are keen

to seek ever more intense experiences and to get them faster and more easily than before. One of the places they turn to in search of these experiences is the virtual world. Travelling will assume ever greater significance as a source of adventure and experiences.

- **Managing changes.** Global dependence was earlier understood primarily in ecological or military security terms. Today, it is understood first and foremost from the point of view of capital and investment markets, production networks and information flows. Many of the new challenges and means of governance are related to the deepening of cooperation between governments and businesses and industries in which the goal is to strengthen national competitiveness in the global competition. States continue to remain important actors, but they now have to work more closely with other, domestic and more often international actors in seeking to safeguard national interests. There are many weak and strong signals which indicate that the role of nation-states in their traditional functions is increasing again. The battle for natural resources and energy in particular is intensifying and more and more often the adversaries in this battle are national governments and global corporations. Competencies related to governance and the assessment of systemic risks is set to gain increasing importance.

The core of the foresight project comprised ten expert panels.

Table 4. Finnsight2015 – expert panels and focus areas of competence.

Expert panel	Focus areas of competence
Learning and Learning Society	The neurological, cognitive, motivational and social basis of learning Human technologies that support learning Technology-based working and operating environments, management of mobile and distributed work Practices of life-long learning, the education system and informal learning Civic skills and competencies, life control and social innovations
Services and Service Innovations	The promotion of a customer and consumer approach Business competence in services The development of better housing, service and work environments The promotion of service exports Data security and information and communications technology in services Culture and adventure services The renewal of public services
Well-being and Health	Biomedical research Brain and neuro research The development of icts that promote public health Physical exercise and nutrition research Mental health and substance abuse research Home care and telecare technologies Pharmaceuticals research Research supporting the social and health care system

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Expert panel	Focus areas of competence
Environment and Energy	The operation of ecosystems The management of environmental issues in finland and globally Urban environments Water systems and water cleaning technologies Biomass as an energy source and biomass production technologies Improved energy efficiency or "negawatts" New energy production systems and their integration Smart sensors and new energy conversion and storage technologies Logistics, distribution Mobile and distributed technologies as a platform for energy and environmental services
Infrastructure and Security	Environmental know-how and technology Logistic know-how and security of supply management Multicultural know-how Integration know-how Methods know-how Russia know-how
Bio-expertise and bio-society	The complete use of renewable natural resources The development of bioproduction New biotechnological product introductions The development of pharmaceuticals Measurement methods and diagnostics Management and modelling of biological knowledge Multidisciplinary synergy and new disciplines
Information and Communications	Communications technology Interaction, usability, user interfaces Sensor technology applications Data mining, analysis, management and retrieval Telecommunications Service development Reforming traditional industry Digital information infrastructures in society Software industry Bioinformation technology Hardware industry
Understand-ing and Human Interaction	Human interaction, understanding and dialogue Multicultural competence Language and communications Life-long learning and understanding People and media Human technology Human creativity Increasingly intelligent technology Deep understanding of own culture

Expert panel	Focus areas of competence
Materials	Technology transfer, innovation chains and processes Printed electronics New surface techniques Specialised and effective use of wood, biomass and renewable natural resources Cost-effective, environmentally friendly steel products Biomimetic materials New carbon materials Multidisciplinary and cross-technological applications in health care Photonics materials development Electronics materials development Biomaterials and bioactive materials Controlled synthesis of polymers
Global Economy	Assessing and managing global risks The impacts of business globalisation on national economies Exploiting global knowledge Reforming the public sector, the prerequisites for taxation, and public acquisitions Enhancing the production and exports of services Promoting and managing the innovation process New research challenges International migration

5.5. European Foresight Monitoring Network Issues Analysis

The European Foresight Monitoring Network (EFMN) is one of a coordinated series of initiatives funded by the European Commission to support the professional development of foresight practitioners in Europe called the Foresight Knowledge Sharing Platform. The EFMN is a network of policy professionals, foresight experts and practitioners as well as analysts of Science, Technology and Innovation related issues. Its primary aim is to develop foresight related content and to gather information about foresight projects from all over the world by means of a mapping process carried out by an international consortium.

On an annual basis, the EFMN issue analysis exploits the outputs of the mapping of foresight exercises. In 2007 the issue analysis exploits the topic of the "European Knowledge-based Economy and Society" aiming at identifying and analysing key emerging science and technology issues relevant for European Union policies (Rijkers-Defrasne et al, 2007). The issue analysis reports on several perspectives identified and highlighted as important features, drivers and trends of the emerging knowledge society:

- **Globalisation** is seen as one of the main drivers shaping the future of the knowledge society, encompassing such diverse aspects as: Removing of barriers to trade and investments in business and services; Further development of global digital media markets due to the diffusion of new (mobile) ICT applications; Greater use of IT to coordinate distributed decision-making and innovation activities on a world; Globalisation of available knowledge due to the diffusion of ICT; Globalisation of R&D and innovation activities - in the public sector as well as in private companies; Globalisation of the market for competent workforce; Emergence of new global organisational and business structures facilitated by the diffusion of ICTs and increasing ubiquity; Increasing mobility of ideals, cultures and values.

- **Ubiquitous / pervasive computing** and "hybrid" technologies. The future developments will be characterised by the increasing convergence of telecommunications networks and computers, and information and communication becoming increasingly ubiquitous. The foresights highlighted the following trends: The size and complexity of software is expected to further grow; Large-scale computing and GRID-type networks will increasingly be used; Data, sound and images are now being transmitted over the same networks and the same terminals can be used for the use of different types of contents; Mobile technologies are more and more widely used for both content production and reception and by 2015, virtually all people living in industrial countries will have access to multimedia services based on mobile or other terminals

- **Innovation** and the shift to a **service based econom**y. The following aspects will impact on and foster the innovation capacity in the knowledge society: Access to knowledge; Availability of suitable legal framework for innovation; Existence of Public-Private-Partnerships and innovation networks between research and industry; Existence of public financial instruments for long-term industrial R&D; International cooperation in the innovation process; Availability of international and open standards for innovations; Support of SMEs in innovation processes; Integration of basic scientific and technological know-how with business, cultural, legal and societal competencies; Efficient technology and know-how transfer between research and industry; Knowledge of consumers' wishes and choices; Promotion of open innovations and customer-driven product development efforts.

- **Labour market**. The foresight studies highlight the trend towards distributed business and organisational networks scattered around the globe and managed and administered via ICT networks. Working in distributed and cross-border networks will pose new challenges regarding the management of work and of increased communication needs including management of knowledge in distributed networks. Due to the increasing complexity of organisations and the increase of new and complex knowledge to manage the following aspects will be in focus: Lifelong learning will become a necessity; Cooperation across areas of expertise and therefore formal and informal knowledge-sharing in networks will become increasingly important; It will be become of increasingly importance to develop cross-cultural, social and communication skills to make multiculturalism an asset supporting the success of international business networks and industries.

- **Education and training & lifelong learning issues.** Learning to learn remains the best guarantee for students to be able to go on with their educational careers, whether in formal or non-formal settings. One of the skills needed for learning to learn is 'information literacy', defined as the ability to locate, classify and sort information. Due to the expected increasing complexity of organisations and their management and leadership, people involved in network organisations will face growing competence challenges, most significantly with respect to the development of diversity as well as interaction, communications and social skills.

- In accordance with the main goals and actions defined in the recent Green Paper on the **European Research Area**, the following aims are highlighted: Development of 'centres of excellence'; Improve human skills; Promotion of international cooperation in R&D; Improvement of the mobility of researchers; Promotion of interdisciplinary research in order to make the full potential of new 'hybrid' innovations and technologies; Promote Private-Public-Partnerships for Research; Concentration of R&D on frontrunner projects - especially for small countries with limited resources.

- The use of **environmental technologies** goes far beyond the production of devices to clean up pollution. It involves the concentration of resources to develop and implement: 'integrated' technologies to prevent pollutants being generated during the production process; new materials; energy and resource-efficient production processes; environmental know-how; new ways of working. Growing climate threats and the scarcity of raw materials have furthermore created a strong global trend to develop and adopt new environmental and energy solutions. Trends related to **sustainable development** are: advanced geoinformatics will provide a solid foundation for tackling many environmental issues; new markets are emerging for sustainable development products, most particularly in two areas of expertise and competence: first, in urban environments and water systems, and second, in water cleaning technologies; the energy sector is moving increasingly to the use of rapidly renewing raw materials; increasing energy efficiency will become increasingly important; growing demand for distributed energy networks; the partial internalisation of environmental costs will influence the relative viability of a number of environmental solutions characterised by marginal competitiveness; nanosciences and nanotechnology will have a significant impact on the energy sector in the years to come.

- **New forms of governance**. The emergence of the Knowledge Society is not expected to have only an impact on the economy or R&D but also on governance and on the way policy is made and implemented. Traditional governance structures are expected to be replaced by new forms of governance adapted to the requirements and needs of the Knowledge Society. As promoted by the e-governance strategy followed by the EU, e-governance applications are expected to ensure: universal access to information; openness and transparency; participation; equity; accountability; effectiveness; coherence; quality of e-services.

- **Coping with increasing risks.** The emerging societies are also ‘risk societies’ characterised by uncertainties, threats and risks increasingly needing to be confronted when decisions are taken and in the course of consequent actions. The Knowledge Society is expected to face new risks and it has to cope with those in the framework of: scientific and technology innovations (risk governance in science); the relationship between science and public opinion (mistrust, etc.); the lack of people’s trust in the ability of institutions to cope with global threats; the increasing dependence of the Knowledge Society on complex ICT networks and the related vulnerability.

5.6. OECD – Science, Technology and Industry Outlook

The OECD Science, Technology and Industry Outlook points at the following broad trends and dimensions of change in the global economy:

- the absolute growth of R&D and innovation related activities; the rise of the BRICS economies in scientific and technological fields; significant globalisation of R&D; more performance of R&D in the service sector and a growing focus on non-technological innovation; widespread policy shifts towards fiscal incentives for R&D; and enhanced internationalisation and mobility of higher skilled people, including greater participation of woman in HRST labour force across almost countries (OECD, 2008, p18)

In OECD countries, there is considerable policy interest in a range of new technologies that promise growth opportunities or solutions to pressing and social and economic problems. These include most notably biotechnology and general life sciences, nanotechnology, and environmental sciences and technologies (OECD, 2008, p33-p36).

- Biotechnology has some particular features. It involves a large numbers of small firms. Many of these firms are linked to universities, so there is a close link between university funding and biotechnology research and outcomes.
- The share of nanotechnology in total national patenting has increased markedly between 1996-98 and 2002-04 in the majority of countries, although the total amount of patenting remains low.
- Environmental technologies are attracting considerable more policy attention as a result of growing concerns about climate change and enhanced public awareness of this issue across the globe. Many governments view technological innovation as a means to promote sustainable development, and public policy can play an important role through public R&D expenditures, fiscal reforms, tax-based measures etc. Key fields include the treatment and management of solid waste, renewable energies, and reduction of green house gases from motor vehicles. Patenting in key environmental technologies, such as renewable energy, is growing sharply.
- The ICT sector invests heavily in R&D. In 2004, ICT manufacturing industries accounted for more than a quarter of total manufacturing R&D expenditure in most OECD countries, and over half in Finland and Korea.

Main trends in science, technology and innovation policies are (OECD, 2008, p58-p60):

- The globalisation of R&D and more open innovation models are challenging national policy making.
- Medium- and long-term national S&T plans include more quantitative objectives and monitoring elements.
- Several countries have strengthened institutional mechanisms for S&T governance.
- Countries continue to focus on key research and technology fields such as ICTs, health, nanotechnologies and energy, but social issues are increasingly a focus of science, technology and innovation policies.
- Reform of funding mechanisms for research institutions to link budget allocations to performance evaluation is becoming more widespread.
- Efforts are made to reduce fragmentation and create critical mass and excellence in the public research sector.
- Support for business R&D and innovation continues to increase and is characterised by focusing of streamlining of programmes and improving ease of access and use, especially for SMEs.
- Networking and cluster initiatives continue to emerge.
- Support for non-technological and user-driven innovation, including in services, is receiving growing emphasis.

- Human resource development is an area of continuous focus and action.
- Evaluation mechanisms and tools are increasing in importance as countries seek to monitor progress in policy making and to assess socio-economic impact.
- Policies to foster demand for innovation, such as the development of lead markets, innovation-friendly procurement and standards, are receiving growing emphasis, in particular in EU.

5.7. ForSociety – Multinational Delphi Survey

ForSociety ERA -Net is a network, where national foresight programme managers co-ordinate their activities and regularly develop and implement transnational foresight programmes.

The Delphi survey is a pilot exercise in a transnational approach in which 15 countries participated (Cakir et al, 2007). The Delphi exercise includes two rounds. The survey focused on statements having 'rupture' potential. A 'rupture' is defined as "a dramatic, highly significant change in the presently-observed trend". 'Ruptures' are interesting as they allow us to move away from the current path and envisage different futures.

The survey comprises five topic areas each with 5 statements.

Table 5. ForSociety – Pilot Multinational Delphi Survey.

Topic	No.	Statement
Policy and governance	1	A robust institutional arrangement for world governance has displaced the UN and can effectively prevent wars between nations
	2	A multipolarised world has emerged, in which Europe efficiently plays a strong role in international governance
	3	The European Union splits into several strongly opposing blocs
	4	Conflicts arise between leading countries to secure access to critical natural resources (oil and gas as well as precious minerals like platinum)
	5	The permanent threat of terrorism is completely incorporated into daily lives of citizens, shaping their mobility choices and restricting their freedom and individual privacy

Topic	No.	Statement
Economy and business	6	Economic globalisation has slowed down, with a majority of consumers now choosing to buy locally produced goods rather than products imported from a long distance away
	7	The dollar is no longer the international monetary standard
	8	Public economic policies are ineffective in a world dominated by large, multinationally organised research clusters, producing companies, financial trusts and media consortia
	9	Most public services (security, transport, education...) are privatised or subcontracted to the private sector
	10	Ageing and a natural reduction in the active population compel the national government to extend compulsory work-time in terms of both hours (more than 40 hours/week) and years (beyond the age of 70)
Society and culture	11	The public social security and pensions system collapses in your country
	12	The rate of immigration from Africa and Asia to your country rises considerably (double the rate in 2006)
	13	In a society in which the public no longer tolerates risk, the "precautionary principle" is now the main criterion when making decisions
	14	The use of private cars has halved. This drastic reduction could be due to a combination of various factors: adequate "on-demand" public transport systems, transport tolls in cities, new public awareness, high oil prices...
	15	Metropolisation comes to an end and people are starting to reinvest in rural areas
Environment and natural resources	16	A worldwide epidemic has occurred, with disastrous consequences for the economy
	17	No technologically and economically viable alternative has been developed "on-time" for widespread use as a substitute to petrol in cars, while oil prices are now well above the production costs of bio-fuels
	18	The management of useable water as a scarce resource is at the origin of serious conflicts in Europe between regions or between professional groups (agriculture, industries...)
	19	The major reduction in biodiversity (40% of known species have disappeared) threatens the whole of humanity
	20	Individual energy production is becoming compulsory and "zero energy" buildings are widespread (every new building is obliged to include in its conception means like solar panels to produce its own energy)
Technology and RDI	21	Technologies that are directly embedded in human bodies and that can communicate and interact with the external environment have become a reality
	22	Breakthroughs in bio- and nano-technologies have favoured the development of environmental technologies allowing Europe to take the lead in the knowledge-based bio-economy
	23	The concept of the Internet as a unique network comes to an end, resulting in division into several independent networks
	24	Fuel cells and hydrogen become a technologically and economically viable solution for car propulsion
	25	The public accepts the development of nuclear energy to complement renewable energies, as a solution that will not alter the global environment in the near future

5.8. Danish foresight work

5.8.1. Green technology foresight

The study identified focus areas with especially promising and strategically important opportunities for Danish trade and industry (Danish Ministry of Science, Technology and Innovation, 2003a):

- Flexible energy systems with increased wind energy: Flexible systems for electricity and heat production are the core in increasing the usage of wind energy, and Denmark is working on a broad front in developing hardware and software.
- Systematic energy optimisation of energy of buildings: Denmark has major potential for achieving energy savings by further developing integrated systems and concepts, especially with opportunities existing in new and smart buildings. Denmark has a competitive advantage in energy savings buildings, new materials, building components, insulation, etc.
- More environmentally-friendly agriculture: The perspectives of targeting precision agriculture and organic farming which are knowledge intensive and enable the targeting of high value crops. Precision agriculture combines IT, remote sensor and robot technology together with further development of traditional agricultural machinery. Organic farming is based on the idea that farming should be part of a natural biological cycle with main aims are to avoid pollution, to maintain/ increase fertility of the soil and work on more closed substance cycles.
- Design of green products and materials: Denmark is at the forefront of the development of green products based on environmentally- friendly materials and processes – i.e. green design.

5.8.2. Technology foresight – biological and health technologies

The study identified the following critical areas (Danish Ministry of Science, Technology and Innovation, 2003b):

- Health problems related to aging, nutrition, and life style
- Health care structure, including shortage of health workers, costs, & management
- Patient relations, focusing on better quality, treatment of inter-related illnesses, personalized care, and more responsibility to the patient
- Ethical issues arising from new technologies and new procedures

To address these issues the following technologies will play a key role in the future:

- Human genomics and proteomics (including products such Personal Genetic ID Cards, prenatal analysis, gene therapy, etc.)
- Stem Cells (for the treatment of neurodegenerative illnesses, traumatic brain and spinal cord injury, etc.)
- Bio-electronics (such nano-robots, biological computing, biosensors, biochips, electronic implants, etc)
- Pervasive Healthcare (such as automatic and mobile monitoring, virtual hospitals, etc)

5.8.3. Technology foresight – pervasive computing

Within a time horizon up to 2012 key technologies include (Danish Ministry of Science, Technology and Innovation, 2003c):

- Communication networks and infrastructure
- Energy saving ICT technology, such as improved batteries and electrical consumption technology
- MEMS - Micro-Electronic-Mechanical Systems, silicon technologies, sensors, micro-mechanical components, etc.
- Screen Technologies such as OLED, LCD and digital paper technologies, etc.
- Software technologies

5.8.4. Technology foresight on Danish nanoscience and nanotechnology

The following technological areas were identified as being critical for the development of the domain and to have a strong relevance for Danish society and its economy (Danish Ministry of Science, Technology and Innovation, 2004): Nanomedicine and drug delivery; Biocompatible materials; Nanosensors and nanofluidics; Plastic electronics; Nano-optics and nanophotonics; Nanocatalysis, hydrogen technology, etc.; Nanomaterials with new functional properties

Coordinated strategy on nanotechnology will need to include a broad range of initiatives: a) prioritise technology areas, b) create interplay between nanotechnological research and high tech industry, c) establish nanotechnology centres for strategic research and innovation, d) increase numbers of higher graduates and researchers, e) spread nanotechnology widely amongst Danish enterprises, and f) attend to potential hazards, and to health-related, environmental and ethical considerations.

5.8.5. Technology foresight on hygiene

In all four research fields are recommended (Danish Ministry of Science, Technology and Innovation, 2005):

- Detection, identification, tracing and risk assessment of microorganisms – The purpose of increased research in the field is to strengthen systems that provide faster and more specific detection of known microorganisms.
- The development, occurrence, dissemination and colonisation of microorganisms – The purpose of the research field is to increase the evidence-based knowledge of evolution and dissemination microorganisms from the reservoir of to the susceptible individual.
- New strategies for interrupting – The purpose of the research is to develop products, methods and techniques to effectively prevent dissemination and growth of microorganisms without causing damage to materials, or the working environment or other inconveniences to humans and animals in the short or the long term.
- Implementation of knowledge about hygiene – A considerable general knowledge about infection prevention and hygiene is not being sufficiently utilised in practice.

5.8.6. Technological foresight – ICT from stable to table

Recommendations Danish Ministry of Science, Technology and Innovation (2006a):

- Denmark shall be a world leader in development and application of user based ICT solutions to agriculture and food production.
- From an international perspective the goal is to develop Denmark to be leading what concerns digital infrastructure and systems integration to the entire value chain from stable to table.
- Denmark has to work for a position as an EU experimentarium for development and testing of new ICT solutions from stable to table.

5.8.7. Technology foresight on cognition and robotics

Research themes and innovation initiatives (Danish Ministry of Science, Technology and Innovation, 2006b):

- Innovation initiatives (short-term): New vision and sensor technology; Production cells; Standard solutions and systems; Toys and games; Improved user interfaces; User studies in robot development; Working environment and safety.
- Application-oriented research (medium-term): Mobile robots that can navigate outdoors and indoors; Robot technology for varied one-off production tasks; Cognitive robots; Multimodal user interfaces; Role division between user and robot; Robots in organisational interaction.
- Basic research (long-term): New materials; Shape-changing and self-repairing robots; Adaptability, stability and dynamics; The robot as a system component; System integration; Intelligent user interfaces; Organic cognition; Embodied cognition; Contributions to cognition through robotics research; Cognitive taxonomy.

Identified megatrends expected to influence the future development and utilisation of robot technology in Denmark:

- **Globalisation**: Globalisation can be defined as growth in economic and societal activities that traverses national and regional borders. Globalisation presents major challenges and opportunities for the future labour market in the form of, among other things, stronger competition for products or the ability to educate and attract qualified manpower.
- **The ageing society**: Ageing in societal terms means more elderly, in both relevant and absolute terms. Whereas in Denmark today there are 3.6 people in the working-age range of 20 to 64 to finance provision for each person under 20 or over 65 years of age, in the year 2030, there will be only 2.5 people. This change in the composition of the population means greater demands in several areas, including health, care, housing and experiences as well as reduced availability of manpower to meet these demands.
- **Knowledge society**: The knowledge or information society is characterised by a dominance of information or knowledge functions. In politics, business and public institutions, knowledge and information, as well as access to them, have become a factor of power and a competitive parameter. Knowledge has become a key word, but knowledge is not

a simple, quantifiable thing. Knowledge production and information technology have required significant changes in company locations, organisation, divisions of labour, etc.

- **Strained resources**: Population increases and economic growth are expected to result in increases in global energy consumption. This is especially the case in the new industrial nations but also in less developed countries. The share of the global energy consumption for these countries is expected to increase from approximately 35 per cent in 1990 to 60 per cent in 2050. At the European level, the total energy demand is expected to have increased by 35 per cent on today's level by the year 2030.
- **Health and security**: Increasing prosperity in the wealthy parts of the world will increase demand in areas such as health and well-being. This will make way for new products and new types of consumption. Security, in its many different forms, will also be of great importance. This includes military and terrorist threats as well as security for the individual in the form of e.g. surveillance and alarm systems.
- **Experience economy**: Also as a result of increasing prosperity in the wealthy part of the world, there is increasing demand for entertainment and experiences. Demand is so great that some say we are developing an experience economy. The experience economy can be described in general terms as a "cross field" where culture and creative powers meet the business community and commercial interests. There is a growing need to balance the increasing technologisation – high-tech – with more human – high-touch – aspects, such as art and spirituality. Companies should no longer only aspire to high-tech, they should also incorporate high-touch dimensions into their products and services.

5.8.8. The Ageing Society 2030

Three main areas (Danish Council for Strategic Research, 2006):

- Healthy ageing with good functional ability and better utilisation of new technological facilities: Prevention & rehabilitation; Potential new forms of medical treatment; Health systems & IT; Everyday technology; Design of housing and clothing.
- An age-integrated labour market with better opportunities for late careers, life-long learning and flexible continuance in employment: Motives for continuing or retiring from the labour market; Senior' skills; The staff policy of the future.
- Cohesion in society – across generations, genders and ethnicity: Increased ration of the elderly and economic sustainability; Political sustainability; The unwritten contract between generations; Grey politics and lobbyism; Wide support for fundamental values.

5.8.9. Technology foresight on mobile and wireless communication

Significant technological and business changes are the next decade expected within the mobile and wireless communication areas. The foresight indicates that (Danish Ministry of Science, Technology and Innovation, 2006c):

- IP convergence will imply that traditional media and devices will converge to a lesser number of portable terminals.

- Wide spread use of personal wireless networks will imply access to all kind of information and communication no matter where you are (at home, at work, on your way, etc.).
- Combines with a large number of sensors, pervasive wireless communication will mean development of several types of intelligent products able to communicate and interact on external inputs.
- The convergence of technologies will also imply convergences in media and business which will challenge present business models and market dynamics.

5.8.10. Green Technological Foresight on Environmentally Friendly Agriculture

The study pointed at a number of potential environmentally friendly technologies (Borch et al, 2004). The perspective for each technology is given in relation to production, environment and landscape and nature-related values:

- Plant gene technology is controversial, but a well-considered application can result in increased and environmental benign production as well as preserve landscape and nature values.
- Information and communication technology includes both decision support systems and a more efficient communication of the latest knowledge about environmentally friendly farming production. The technology does at the same time give completely new possibilities for supervising, modelling and controlling biological environments.
- Manure technologies include knowledge and techniques to handle manure as fertilizer from stable to plants aiming at reduced leaching to the environment.
- Biomass technology consists of technologies that can effectively and cheaply convert biomass into energy and material of high quality.
- Cultivation and soil preparation implies intelligent utilisation of biological and agricultural knowledge and is an effective strategy to minimise environmental impact from agriculture. In short: ‘good agricultural practice’ based on expert systems and ICT.
- Precision farming uses GPS, GIS, sensors and robots to precisely adjust and eventually avoid the use of fertilizer, pesticides, etc., based on knowledge about variations in conditions of cultivation or environmental fragile areas.
- New stable systems focusing on low emission of odour and ammonium by means of stable design, new surface materials, feeding, ventilation, and chemical or biological absorption of odour and ammonium.

6. Observations – strategic scanning >

6.1. Trends and drivers

Drivers of change are factors that in some way will influence the future direction of development, i.e. they can be described as barriers or carriers. Using a tree metaphor (Lindgren & Bandhold, 2003, p83) drivers of change can be characterised as the root system helping to emphasise why a tendency may develop. A tendency being established can be named a trend or a trend cluster, which constitutes the trunk of the tree. The consequences of the trend are shown as branches. The crown of the tree shows the complexity of the development and its consequences.

Megatrends are the great forces in societal development that will very likely affect the future in all areas the next 10-15 years. They commonly used to indicate a widespread (i.e. more than one country) trend of major impact, composed of subtrends which in themselves are capable of major impacts. For example, global climate change will have a major impact, on all the countries of the world, and can be disaggregated into global atmospheric warming, sea-level rise, etc.

STEEPV is an acronym for the six themes for thinking about the future: social, technology, economics, ecology, politics and values. The six themes specify the domains in which appreciation and the reflexive appropriation of knowledge are needed (Loveridge, 1996, 2002). The ecology theme is often misinterpreted as 'the environment, but ecology is a far wider concept being the relation between an organism and its environment. The drivers and trends identified in the strategic scanning have been structured by use of STEEPV themes and subsequent compiled.

Social - drivers and trends

- **The ageing society.** Ageing in societal terms means more elderly, in both relevant and absolute terms. Whereas in Denmark today there are 3.6 people in the working-age range of 20 to 64 to finance provision for each person under 20 or over 65 years of age, in the year 2030, there will be only 2.5 people. This change in the composition of the population means greater demands in several areas, including health, care, housing and experiences as well as reduced availability of manpower to meet these demands. There will be a need for more staff in the service sector as well as in jobs requiring high levels of education.
- **Learning.** Due to the expected increasing complexity of organisations and their management and leadership, people involved in network organisations will face growing competence challenges, most significantly with respect to the development of diversity as well as interaction, communications and social skills. One of the skills needed for learning to learn is 'information literacy', defined as the ability to locate, classify and sort information.

- **Work, labour market and cooperation**. Work is becoming increasingly independent of time and location. More partnerships, distributed networks and cooperation means increased demand for mobility and more communication at micro, mezo and macro level across institutions and expertises. Formal and informal knowledge-sharing in networks will become increasingly important. The open innovation concept will continue to grow and expand with the rapid changes in earning models. Increasing ubiquity is making the distinction between work and leisure increasingly blurred. The key workforce groups are ever more pressed for time and also have increasing purchasing power. Where knowledge workers operate globally, services are needed locally.

Technology - drivers and trends

- **Information is everywhere.** Digital information and networks are paving the way to ubiquitous networking. Government functions and services are increasingly moving to web-based networks, which means they are accessible to all people at all times and in all places. There is increasing convergence of telecommunications networks and computers. The size and complexity of software is expected to further grow. Technological convergence also enables completely new ways in which people can link up to networks both technologically, professionally and socially. This complex web of networks offers greater scope for a new kind of creativity. Data, sound and images are now being transmitted over the same networks and the same terminals can be used for the use of different types of contents. Mobile technologies are more and more widely used for both content production and reception and by 2015.
- **Innovation** and the shift to a **service based economy.** The following aspects will impact on and foster the innovation capacity in the knowledge society: Access to knowledge; Availability of suitable legal framework for innovation; Existence of Public-Private-Partnerships and innovation networks between research and industry; Existence of public financial instruments for long-term industrial R&D; International cooperation in the innovation process; Availability of international and open standards for innovations; Support of SMEs in innovation processes; Integration of basic scientific and technological know-how with business, cultural, legal and societal competencies; Efficient technology and know-how transfer between research and industry; Knowledge of consumers' wishes and choices; Promotion of open innovations and customer-driven product development efforts.

Economics - drivers and trends

- **Globalisation.** Globalisation can be defined as growth in economic and societal activities that traverses national and regional borders. Globalisation presents major challenges and opportunities for the future labour market in the form of, among other things, stronger competition for products or the ability to educate and attract qualified manpower. There are two prominent driving forces in today's global operating environment. The first is the trend of increasing mobility: the flow of goods, money, capital, people, ideas, cultures and values across national boundaries is continuing to expand. The second is the growing interdependence of different parts of the world, their increasing interaction and cooperation in the economy, production, social development, communications and human exchange.

- **Managing changes.** Global dependence was earlier understood primarily in ecological or military security terms. Today, it is understood first and foremost from the point of view of capital and investment markets, production networks and information flows. Many of the new challenges and means of governance are related to the deepening of cooperation between governments and businesses and industries in which the goal is to strengthen national competitiveness in the global competition. States continue to remain important actors, but they now have to work more closely with other, domestic and more often international actors in seeking to safeguard national interests. There are many weak and strong signals which indicate that the role of nation-states in their traditional functions is increasing again. The battle for natural resources and energy in particular is intensifying and more and more often the adversaries in this battle are national governments and global corporations. Competencies related to governance and the assessment of systemic risks is set to gain increasing importance.
- **Knowledge society**: The knowledge or information society is characterised by a dominance of information or knowledge functions. In politics, business and public institutions, knowledge and information, as well as access to them, have become a factor of power and a competitive parameter. Knowledge has become a key word, but knowledge is not a simple, quantifiable thing. Knowledge production and information technology have required significant changes in company locations, organisation, divisions of labour, etc.

Ecology - drivers and trends

- **Sustainable development: a safe option for the longer term.** As well as being ecologically sustainable, our decisions and solutions have to be economically viable, socially just and culturally valuable. Investment in competence on sustainable development is a safe option in the longer term, but it is not clear how and by what means such development can be achieved, and those means are certainly not always profitable in the short term. The world's ecosystems are in a state of accelerating change as a direct result of human activity, but we continue to know too little about those changes. Organisations and their management and leadership are becoming increasingly complex. People who are working full-time in production in advanced countries will be spending more time than before in training and education.
- The use of **environmental technologies** goes far beyond the production of devices to clean up pollution. It involves the concentration of resources to develop and implement: 'integrated' technologies to prevent pollutants being generated during the production process; new materials; energy and resource-efficient production processes; environmental know-how; new ways of working. Growing climate threats and the scarcity of raw materials have furthermore created a strong global trend to develop

and adopt new environmental and energy solutions. Trends related to **sustainable development** are: advanced geoinformatics will provide a solid foundation for tackling many environmental issues; new markets are emerging for sustainable development products, most particularly in two areas of expertise and competence: first, in urban environments and water systems, and second, in water cleaning technologies; the energy sector is moving increasingly to the use of rapidly renewing raw materials; increasing energy efficiency will become increasingly important; growing demand for distributed energy networks; the partial internalisation of environmental costs will influence the relative viability of a number of environmental solutions characterised by marginal competitiveness; nanosciences and nanotechnology will have a significant impact on the energy sector.

Politics - drivers and trends

- **New forms of governance**. The emergence of the knowledge society is not expected to have only an impact on the economy or R&D but also on governance and on the way policy is made and implemented. Traditional governance structures are expected to be replaced by new forms of governance adapted to the requirements and needs of the knowledge society. As promoted by the e-governance strategy followed by the EU, e-governance applications are expected to ensure: universal access to information; openness and transparency; participation; equity; accountability; effectiveness; coherence; quality of e-services.
- **Science, technology and innovation policies**. Countries continue to focus on key research and technology fields such as ICTs, health, nanotechnologies and energy, but social issues are increasingly a focus of science, technology and innovation policies. Support for non-technological and user-driven innovation, including in services, is receiving growing emphasis. Human resource development is an area of continuous focus and action.

Values - drivers and trends

- **Equality in cultural encounters**. With the advance of globalisation, different sets of values are coming into contact with one another more and more often. As the need for competent people continues to increase with population ageing, positive multiculturalism combined with the welfare state is definitely a competitive asset.
- **Experience economy**. Also as a result of increasing prosperity in the wealthy part of the world, there is increasing demand for entertainment and experiences. Demand is so great that some say we are developing an experience economy. The experience economy can be described in general terms as a “cross field” where culture and creative powers meet the business community and commercial interests. There is a growing need to balance the increasing technologisation – high-tech – with more human – high-touch – aspects, such as art and spirituality. Companies should no longer only aspire to high-tech, they should also incorporate high-touch dimensions into their products and services. Young people in particular are keen to seek ever more intense experiences and to get them

faster and more easily than before. One of the places they turn to in search of these experiences is the virtual world. Travelling will assume ever greater significance as a source of adventure and experiences.

- **Coping with increasing risks.** The emerging societies are also 'risk societies' characterised by uncertainties, threats and risks increasingly needing to be confronted when decisions are taken and in the course of consequent actions. The society is expected to face and cope with new risks.

6.2. Technological fields

Foresights deal with thematic classes, which are the elements to be analysed. As described in chapter 4, classification can be done by use of different principles.

According to Barré (2002) there are four options about thematic classes:

i) technology areas and their scientific components, capability and use function
ii) economic and industrial activity sectors
iii) public functions
iv) strategic issues

Inspired by these thematic classes the technological fields identified through the strategic scanning are structured by use of the following thematic classes:

technology or industrial push	science & technology issues
	sectoral issues
societal demand pull	strategic issues
	public functions issues

Table 6. Review – observations on foresight issues.

			The Eighth Japanese Delphi Survey	Key technologies for Europe	UK Foresight – Horizon Scanning Centre	FinnSight 2015	OECD – Science, Technology and Industry Outlook	ForSociety – Multinational Delphi Survey	Danish foresights
Technology or industrial push	science & technology	Biotechnology		x		x	x		x
		Cognitive science		x					
		Electronics	x						
		Frontier	x						
		Information technology	x	x	x	x	x		x
		Life science	x				x		
		Materials	x	x	x	x			
		Nanotechnology	x	x	x		x		x
		Pervasive technologies							x
		Robotics			x				x
		Sensors			x				
	sectoral	Agriculture, forestry, fisheries and food	x	x					x
		Body and mind		x					
		Industrial infrastructure	x						
		Transport		x					
		Services		x		x			
		Social technology	x						
Societal demand pull	strategic	Complexity		x					
		Economy and business						x	
		Energy and resources	x	x	x	x		x	
		Environment and climate	x	x		x	x	x	
		Global Economy				x			
		Green technologies							x
		Learning and Learning Society				x			
		Manufacturing	x	x					
		Network interactions			x				
	public functions	Communications	x	x		x	x		x
		Health, medical care and welfare	x	x		x			x
		Hygiene							x
		Infrastructure				x			
		Policy and governance						x	
		Rural Economies		x					
		Security		x	x	x			
		Social infrastructure	x						
		Social Sciences and the Humanities		x				x	
		Understanding and Human Interaction				x			

7.1 Fifteen focus areas identified by GTS

After the international assessment of the GTS system in the spring of 2008, the assessment panel stated that 'the GTS institutes should jointly select and present reasons for 10 to 20 technological focus areas which are expected to set the agenda for the next two result target agreement periods: 2010-2012 and 2013-2015' (GTS, 2008). As its starting point, the catalogue took the FORSK2015 terminology and categories (Danish Ministry of Science, Technology and Innovation, 2008).

This section contains a review of the GTS focus areas plus a brief comparison of each area with the findings in the science and technology foresight studies reviewed. The text and quotations in the boxes are selected examples from the GTS catalogue, and the comments below the boxes are assessments by the authors of this report.

7.1.1 Area 1 : Future energy systems

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The prognosis up to 2050 indicates growing energy consumption, stagnating – and later falling – oil production and increasing climate change. There are therefore major challenges involved in creating and developing the energy technologies and systems of the future, which will have to provide sufficient, stable and intelligent energy services at a competitive price and with a minimal impact on the climate and surrounding environment in general.	> Energy sources & production: reduction of the consumption of fossil fuels, reduction of CO_2 and other pollutants > Energy distribution & storage: solutions for distribution and storage > Energy consumption: energy saving technologies, optimal utilisation of accessible energy

Comments

Issues related to energy are high on the agenda in nearly all the foresight studies included in the review, and energy is treated as a separate issue. These issues include efficient energy conversion and use, clean technologies, hydrogen energy systems, fuel cells, renewable energy, biomass, decentralized energy systems, nuclear power, process integration, energy optimization, construction materials and flexible energy systems.

In general, there is good compliance between the studies reviewed and the GTS2015 fields and trends as far as energy is concerned. GTS2015 has a stronger and more specific focus on energy conservation, renewable energy in general and wind turbines in particular, reflecting strong and highly regarded Danish technology and market positions.

Internationally, there is a focus on nuclear fission and fusion but, due to Danish political priorities, these technologies are not focus areas in Denmark.

7.1.2 Area 2 : Future climate change and climate adaptation

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The expected climate changes in Denmark within the next 100 years include rises in temperature of 2-4°C, changes in annual rainfall distribution and intensity, and changes in prevailing wind directions and storm intensity as well as a rise in the average sea level of about 0.5 metres.	> Reduction of climate and environmental impact: reduce adverse environmental effects (CO2, biological and chemical particles) > Adapting to climate change: adapting our production and behaviour to current and imminent climate change

Comments

In the studies reviewed, issues related to climate are usually treated as part of issues related to energy or the environment or sectoral fields such as transport. In some foresight studies, climate change is seen as megatrend rather than a technology focus area.

There is good compliance between GTS2015 and the studies reviewed: both have a strong focus on especially technologies, systems and process changes targeting CO_2 reduction. Further, biotechnology and biology are emphasized, with a focus on biomass as an energy source, biomass production technologies, and new plants and crops adapted to the new world environment. GTS2015 and the studies also point out the fields of measurement and sensors.

Our review identifies an increasing need for a stronger orientation towards management and competencies related to governance in order to cope with climate-related issues.

7.1.3 Area 3 : Competitive environmental technologies

Trends and needs (GTS2015)	Central technological fields (GTS2015)
In many parts of the world the pressure on the environment is mounting as a result of economic growth and increasing consumption.	> Technology & process: control, management and measurement of environmental technological processes > Purification and cleaner technologies targeted at specific media: technologies aimed at such specific media as water, soil and waste

Comments

Environmental technologies cover a broad spectrum of technologies, methods for environment impact analyses, and resource and environmental system management.

In general, the GTS2015 focuses on technological solutions, whereas the studies reviewed – especially 'Key technologies for Europe' – put more emphasis on the need to combine technological and organizational/social innovation. Further, the 'Key technologies' study stresses the need for new radical technological solutions.

From an overall perspective, there is good compliance between the GTS2015 focus areas and the five main areas of environmental technology future research identified in 'Key technologies': environmental system management and policy, generic technologies, sector-specific technologies, green products and services, and the modelling of society-ecology interactions.

7.1.4 Area 4: Bio-resources, foodstuffs and other biological products

Trends and needs (GTS2015)	Central technological fields (GTS2015)
Biological production today has a number of challenges and opportunities, due both to rising global demand for foodstuffs and bio-energy, and new consumer demands concerning ecology, health, taste and ethics. It is also, however, due to the fact that it has become increasingly necessary to take account of effects from "soil to table", as well as from "table to soil".	> System approach: technologies at the system level where there is a considerable potential in applying technology to processes across the value chain > Primary production: agriculture, fishing and aquaculture > Secondary products and processes: technologies which focus on processing

Comments

Biological production and food production are treated as separate areas in most of the foresight studies, although not in the UK Foresight Horizon Scanning or Finnsight. Especially 'Key technologies for Europe' has a strong focus on the ongoing reform of the Common Agricultural Policy (CAP) and the new demands and requirements following from the policy.

Both GTS2015 and the studies reviewed point to the future challenge to biological production due to rising global demand for foodstuffs and bioproducts and to consumer demands concerning ecology, health, quality and ethics.

The 'Key technology' study underlines the need to develop knowledge-based multifunctional agri-food industries that support the repositioning of rural regions/economies in the knowledge economy.

The GT2015 underlines aquaculture as a central area, but aquaculture was not identified in the studies review.

7.1.5 Area 5 : ICT – support for efficiency, productivity and innovation

Trends and needs (GTS2015)	Central technological fields (GTS2015)
New information and communication technology can play a significant role in encouraging more efficient use of resources, both material and human.	> Applications: support concrete applications and related interactions with users > Core technology/infrastructure: handling massive amounts of data, distributed systems > Process & method: innovation including user involvement

Comments

Information and communication technologies are considered of great importance and are very high on the agenda in all the foresight studies reviewed. There is good compliance between these studies and GTS2015.

ICT is a generic group of technologies with a huge number of applications and opportunities which are expected to support all sectors in some way or another.

7.1.6 Area 6: The production systems of the future and0 Denmark's competitiveness

Trends and needs (GTS2015)	Central technological fields (GTS2015)
In Denmark the existence of a high wage level and increasing global competition from low-wage countries lead to a growing need for the development of production systems that can contribute towards freeing up human resources for more knowledge intensive jobs through automation and other technological support.	> Globalisation and competitiveness: multidisciplinary development across technical disciplines and social and commercial knowledge pools > Production technology/robot technology: plastic technology, tribology, micro- and nanotechnology, sensors, robotics, intelligent mechanical automation solutions

Comments

This focus area is specific to GTS2015. The fields mentioned – e.g. multidisciplinarity, micro- and nanotechnology, robotics, sensors and intelligent technological solutions – were also identified in the studies review, as was the general trend towards knowledge-intensive jobs in the labour market and human resources.

There is an overlap between this area and Area 7 (strategic growth technologies), since both emphasize robotics, micro- and nanotechnologies, and sensors.

7.1.7 Area 7 : Strategic growth technologies

Trends and needs (GTS2015)	Central technological fields (GTS2015)
In the face of increasing global competition, it is becoming ever more apparent that Danish companies' place in the global market is dependent on their consistent ability to raise the knowledge content in both products and processes.	> Material technology – micro and nano: thin film, metrology, structured materials, coating, etc. > Sensors, ICT and robot technology: sensors, actuators, monitoring, interfaces > Cell and organ technology: biological and artificial tissue, organ and cells, polymer and non-polymer materials for the health sector > Others: e.g. biocompatible materials for the health sector

Comments

The concept of strategic growth technologies is specific to GTS2015. There is a rather large overlap between this focus area and Area 6 (future production systems and Denmark's competitiveness) and Area 8 (future health and prevention).

The technological fields identified are in good compliance with what we found in the foresight studies we reviewed, although it should be mentioned that these fields not are treated as a single coherent field in the science and technology studies included in the review.

7.1.8 Area 8: Future health and prevention

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The pressure on the health system will increase dramatically over the coming years. The reason for this is the larger proportion of elderly people in the population with the attendant age-related diseases, combined with a drastic increase in lifestyle diseases across all age groups, plus the fact that a number of previously fatal diseases are today no longer fatal but result in more long-term chronic suffering.	> Diagnostics, prevention and lifestyle: rapid and advanced diagnostics and prevention > Treatment: individual tailored treatment > Development of drugs and bio-materials for the future: combined mathematical and laboratory models of cells and organs which can be used to simulate diseases and test the effects of different drugs

Comments

Healthcare, quality of life, pressure on the health system due to an ageing society, and the increasing convergence of nanotechnology, biotechnology, ICT and cognitive science are technology areas and trends that can be found in nearly all the foresight studies reviewed.

GTS2015 has a strong focus on healthcare and advanced medical technologies due to Denmark's long experience in research and development and strong business positions in the pharmaceutical and medical sector.

7.1.9 Area 9: Innovation – accelerated development of new products

Trends and needs (GTS2015)	Central technological fields (GTS2015)
Large multinational market leaders are increasingly using new tools to boost their innovation processes, for example open innovation, global knowledge banks established through new opportunities opened up by the internet. In addition, many companies work professionally with user-driven innovation.	> Technology: technologies aimed at accelerating the innovation process, perception technologies linked to user preferences > Methods: collaborative interplay between different technical disciplines

Comments

Innovation is a generic issue across sectors and technology fields. In most foresight studies, the need for innovation and new development is regarded as a trend or policy interest, and as a result the studies have a broader perspective than GTS2015 and also include fields as governance, management and policy measures.

Foresight is transdisciplinary, viewing modern knowledge production as a process transcending both disciplines and institutions. The GTS2015 methodological perspective on the collaborative interplay between different technical disciplines is in good accordance with the transdisciplinary understanding of knowledge production.

7.1.10 Area 10: The public sector of the future – the need for labour-saving technology

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The public sector is currently facing a number of major challenges. This is partly due to the fact that the population is getting older leading to all the attendant pressures on the care sector and an increasing need for treatment for very treatment-intensive diseases. Another reason is the growing challenge arising from the shortage of labour, resulting from the demographic shift as large numbers of public sector employees retire without the equivalent numbers of people available to replace them. Finally, it is also due to increased expectations for a demand-driven individually tailored public service from both private individuals and other players.	> Technology: technologies that could lead to concrete solutions in labour-saving technology, e.g. robot technology, intelligent products > Organisation and behaviour: covers a range of 'softer' technologies such innovation in work organisation and work processes and improving incentives for, for example, public tenders.

Comments

Most foresight studies do not have a specific focus on the public sector, which is regarded as a heterogeneous sector applying nearly all kinds of technologies. For this reason, Area 10 is not directly comparable with a corresponding field from the studies review. It should be mentioned that the central technological fields are in good compliance with the outcome of the review.
Furthermore, there is an overlap between this focus area and Area 6 (future production systems and Denmark's competitiveness) and Area 11 (service innovation).

7.1.11 Area 11: Service innovation

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The service sector is today by far the largest sector in Denmark, accounting for 70 per cent of Denmark's gross value added. More than eight out of ten new jobs are created in the service sector.	> Technology: service innovation rooted in the conversion of technology and services covers fields which use technological successes as a basis for service innovation. > Process and organisation: covers soft technologies enabling service innovation through new processes and organisation, including new forms of systematic innovation in the shape of 'Service Engineering' or user- and employee-driven innovation.

Comments

'Key technologies for Europe' points out that there is little knowledge about how to develop, design and model service-driven innovation processes systematically, and that a better understanding of the interrelationship of service and innovation processes could lead to sustainable enforcement of international competitiveness. 'Key technologies' also calls attention to the fact that the rapid integration of European economies requires new answers from European-oriented service research. Thus there is good accordance between the studies reviewed and GTS2015 with respect to the need for research and development in new forms of service and to the fact that there are a number of major challenges involved in an extensive expansion of service innovation.

Both 'Key technologies' and GTS2015 emphasize the rapid growth of the service sector and the importance of the service economy.

7.1.12 Area 12: Sustainable infrastructure (utilities, transport, communication and planning)

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The future infrastructure faces a number of challenges, including, firstly, finding solutions to the urgent problems posed by transport. Secondly, they include making sure utilities systems are efficient and reliable, and dealing with the many side-effects caused by ongoing climate change. But there is also a pressing need for radical new ways of thinking, for example in the form of the development of technologies and a supporting infrastructure for the substitution of fossil fuels, concepts such as sustainable green cities or the fusion of ICT solutions with infrastructure on a strategic level to handle new utility and transport systems, etc.	> Utilities: technology to ensure a sustainable utilities infrastructure > Infrastructure: infrastructure on a broad, overall perspective > Transport: solutions to the challenges inherent in the transport sector

Comments

The importance of infrastructure issues is emphasized in nearly all the foresight studies. Infrastructure is not a well-defined area, so the descriptions and definitions given vary. Examples of classifications used are social infrastructure and industrial infrastructure. Infrastructure is a huge area, with traffic and transport regarded as urgent problems often treated separately in foresight studies.

The strong focus on sustainable infrastructure (transport, water, ICT, etc.) in GTS2015 is in good accordance with the findings of our review, with importance attached to management and infrastructure in both the review and GTS2015.

7.1.13 Area 13: Education, training and lifelong learning – sustainable innovation

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The quality of human capital is critical to our future prosperity and welfare. Investment includes measures to enhance the capability in our education system to implement and sustain systemic innovation. Secondly the aim is to ensure that the development of innovative competences becomes an integrated component in the educational supply. Initiatives must comprise an interplay between formal education and training and on-the-job training to en-sure efficiency and coherence in approaches. A deeper insight in those factors that drive innovation could result in a knowledge – and evidence based approach to services offered, both with regard policy development for sustainable innovation as well as at the specific enterprise level.	> Learning technologies: technologies that can support companies, especially SMEs, in supporting the innovation potentials by involving employees more broadly in innovation processes > Development process: technologies aimed the need for traceability and documentation in a competitive, globalised world

Comments

Only Finnsight2015 has 'learning society' as a specific issue. Other studies view learning, e.g. lifelong learning, as a trend more than a field. Nearly all studies include issues related to education, training, human resources and competence development.

GTS2015 has a great deal of emphasis on the development and dissemination of learning technologies supporting SMEs in the development and exploitation of the potential of their employees, and this focus reflects the Danish occupational structure of many small companies not having the resources themselves.

7.1.14 Area 14: Health and safety and their interaction with environmental factors

Trends and needs (GTS2015)	Central technological fields (GTS2015)
The need for players who can provide advice and consultancy services to companies at the interface between chemical, physical and micro-biotic processes on the one side and health and the environment on the other is growing.	> Sorting, treatment and recycling of waste: technologies that tackle the challenges thrown up by both waste and industrial emission in the broadest sense > Cleaner technology: hygiene, substitution > System approach: holistic perspective on combination of methods and/or technologies

Comments

Environmental and cleaner technologies are assigned very high importance in the foresight studies. The development of these types of technologies is strongly driven by public and political opinion on the need and demand for sustainable development.

There is good compliance between GTS2015 and the studies reviewed on the need for a holistic perspective on environmental issues and on the fact that the use of environmental technologies goes far beyond the production of devices to clean up pollution.

7.1.15 Area 15: Better lifespace – space for live and growth

Trends and needs (GTS2015)	Central technological fields (GTS2015)
Living space can be defined as the interplay between physical space and social processes. It is important that space in society is arranged such that it meets people's needs and is not harmful to health or the social processes that occur within it.	> Physical environment: technologies aimed at the development and improvement of the parameters that determine the quality of people's living space > Perceptions and experiences: technologies for the optimisation of how people experience the living space they move about in

Comments

Area 15 is oriented towards spaces and the social processes that occur within them. Similar issues and fields can be found in the studies reviewed, although they mostly have a broader perspective than just space, e.g. well being, healthcare, social technology and security. Also cognitive science can contribute to the development of living spaces.

With this focus area, GTS2015 has formulated an area that is in good compliance with the findings of the review, but more narrowly defined.

7.2 GTS focus areas and the studies review: An overview

The purpose of this chapter is to compare the GTS2015 focus areas and the outcome of our review of science and technology foresight studies.

Our intention here is to provide an overview and sketch a general picture of the similarities and differences between GTS2015 on the one side and the studies reviewed on the other to help identify future opportunities and challenges for GTS institutions. The intention is not to go into detail, neither on trends nor on technological fields.

It must be stressed that an exercise of this kind is generally subject to uncertainties and open questions. First, the observations of the review were summarized using one way to classify and structure both foresight issues and trends. Second, it must be remembered the comparison of the review outcome with GTS2015 is the result of our own personal judgement. The comparison is made in a tabular form to maintain the overall picture.

7.2.1 Technology fields

Technological fields: The general picture

The overall picture (Table 7) is one of good compliance between the GTS2015 issues and the issues identified in our review. Especially issues with a high degree of attention and alertness in both national and international communities have a high focus and representation in nearly all the foresight studies reviewed as well as in GTS2015. These issues are ecology, energy, health and ICT.

There are overlaps between the 36 technological fields identified in the review, for example between ‘green technologies’ and ‘environment and climate’ and between ‘information technology’ and ‘communication’. The different classification principles and process approaches used in the foresight studies make it nearly impossible to establish a consistent and unambiguous platform for comparison.

It must be noted that neither the review nor GTS2015 make judgements concerning weighting or prioritisation of significance among the different fields and areas. Further, the number of ticked boxes in the table is not an indication of significance of the field in question, only a reflection of whether the field is included in the foresight studies in question.

Table 7. Technology fields: comparison of review and GTS2015.

			The Eighth Japanese Delphi Survey	Key technologies for Europe	UK Foresight: Horizon Scanning Centre	FinnSight 2015	OECD: Science, Technology and Industry Outlook	ForSociety: Multinational Delphi Survey	Danish foresight studies	GTS2015 focus areas
Technology or industrial push	Science & technology	Biotechnology		x		x	x		x	4, 7, 8
		Cognitive science		x						15
		Electronics	X							6, 7
		Frontier	X							7
		Information technology	X	x	x	x	x		x	5, 7, 10
		Life science	X				x			8
		Materials	X	x	x	x				7, 8
		Nanotechnology	X	x	x		x		x	6, 7
		Pervasive technologies							x	6, 7
		Robotics			x				x	6, 7, 10
		Sensors			x					6, 7
	Sectoral	Agriculture, forestry, fisheries and food	X	x					x	4, 7
		Body and mind		x						8
		Industrial infrastructure	x							5, 7, 12
		Transport		x						12
		Services		x		x				10
		Social technology	x							10
Societal demand pull	Strategic	Complexity		x						6
		Economy and business						x		6, 7, 9
		Energy and resources	x	x	x	x		x		1, 12
		Environment and climate	x	x		x	x	x		2, 3, 4, 6, 12, 14
		Global economy				x				7, 9
		Green technologies							x	1, 2, 3, 12
		Learning and learning society				x				13
		Manufacturing	x	x						4, 6, 7, 9
		Network interactions			x					5, 7, 9, 10
	Public functions	Communications	x	x		x	x		x	5, 7, 9
		Health, medical care and welfare	x	x		x			x	4, 6, 8, 10, 14, 15
		Hygiene							x	4, 14
		Infrastructure				x				10, 12
		Policy and governance						x		
		Rural economies		x						
		Security		x	x	x				4, 14
		Social infrastructure	x							10, 12, 15
		Social sciences and the humanities		x				x		9, 15
		Understanding and human interaction				x				10, 15

Issues related to policy, governance and regional development

Issues related to policy, governance and rural development are more conspicuous in the studies reviewed than the issues presented and recommended by GTS2015. This divergence is not surprising. First, the aim of foresight studies is to identify and prioritise opportunities for future development, and the recommendations are time and again targeted decision-makers and their influence through policy measures and instruments. Second, as regards the Lisbon strategy, regions are expected to play a core role in the development of the European Research Area and are often seen as an appropriate arena for realising innovations; this political agenda is reflected in many foresight studies.

Danish niches and strength positions

The comparison made here does not point to any particular Danish niches or strength positions. The foresight studies on science and technology that we reviewed were nearly all performed at a rather high level of aggregation which provides a helicopter perspective on technological and societal developments. This high-level exercise does not leave any room for lower-level specific technological issues and niches addressing the Danish occupational and business structure. GTS2015 contains assessments and descriptions of Danish commercial strengths.

Technology pull or societal push

The technological fields identified in the strategic scanning process are in this report organized into thematic classes related to ‘technology or industrial push’ and ‘societal demand pull’. We employed our best judgement in placing each of the 36 fields in a thematic class, and it must be stressed that it could have been done in other ways. For this reason, it is impossible to draw very strong conclusions on the distribution of the fields among the thematic classes, although it does seem that issues related to ‘societal demand pull’ are higher on the agenda than issues related to ‘technology or industrial pull’, especially as far as the technological focus areas from GTS2015 are concerned.

Role of expectations and replications

In any interpretation of the comparison we make in this report, attention should be paid to the role of expectations. The starting point for GTS2015 is to some extent FORSK2015, and the input for FORSK2015 is to a certain extent inspired by foresight projects and other kinds of future studies. Furthermore, some of the studies we reviewed refer to other studies within this same group. It would be very difficult to determine exactly to what extent the same basic key sources were used in the different studies and to what extent the our review and GTS2015 are based on the same sources. A key task in the interpretation is critical reflections on the dynamics of issue identification processes, e.g. incentives, motives, funding and influence.

7.2.2 Trends

General picture of trends

As for the technological fields, the general picture (Table 8) is one of good compliance between the GTS2015 trends and the trends identified in the foresight studies we reviewed. Especially trends with a high degree of attention and alertness in both national and international communities have a great deal of focus and representation in nearly all the foresight studies reviewed and in GTS2015. These issues are ecology, ageing society, innovation and knowledge society.

We structured the trends identified in our strategic scanning using the STEEPV approach, which can be characterized as a checklist structure; where in the STEEPV structure we placed each trend was a judgement call on our part. In the foresight studies, trends are identified for different reasons and described in different ways and at different levels. The location of trends in the checklist structure together with the summing-up of different types of trends gives rise to our recommendation not to draw too strong conclusions on the trends in the six STEEPV classes.

Table 8. Trends: comparison of review and GTS2015

STEEPV	Identified trends	GTS2015 trends and needs
Social	The ageing society	8, 10
	Learning	13
	Work, labour market and cooperation	5, 9
Technology	Information is everywhere	5
	Innovation and the shift to a service based economy	5, 9
Economics	Globalisation	6
	Managing changes	9
	Knowledge society	5, 6, 7, 9, 13
Ecology	Sustainable development: a safe option for the longer term	1, 2, 4, 10, 12, 14, 15
	Environmental technologies	1, 2, 3, 12, 14
Politics	New forms of governance	
	Science, technology and innovation policies	6, 7, 9
Values	Equality in cultural encounters	
	Experience economy	
	Coping with increasing risks	4, 14

Value and culture trends
Trends related to values and cultures have a higher representation in the studies reviewed than in GTS2015. Values are high on the political agenda, also in Denmark. As a result of globalisation and the EU enlargement, the flow of goods, money, capital, people and ideas across national boundaries continues to expand, challenging national cultural understandings, traditions and behaviour. For this reason, it may be a good idea to put more emphasis on values in GTS2015.

Experience economy

Special attention should be paid to the ‘experience economy’ trend, which has a rather low awareness in GTS2015. The experience economy concept has gained much favour over the past decade and set a new agenda for products and services. Experience and creative content are becoming increasingly important elements of any product or service as the decisive competitive edge. Knowledge-intensive industrial manufacturers acknowledge that the immaterial dimensions of both their products and their brand/organization are becoming increasingly important to address.

7.3 Interviews

The findings of the review presented here and the comparison with GTS2015 were discussed with two external experts: one from the business sector and one from technological research, with a view to supplementing and challenging our findings. The interviews were held by telephone in the form of qualitative interviews. Prior to the interviews, we sent background materials to these experts, including summaries of the 15 focus areas from GTS2015 and the technological fields and trends identified from the foresight studies we reviewed. The following questions and requests for comments were also sent to the experts before they were interviewed:

- We would like your comments and remarks on the technological fields and trends identified in the foresight studies reviewed.
- We would like your comments on the 15 technological focus areas specified in GTS2015.
- Our comparison of the two indicates a high degree of attention and alertness to technological challenges related to health, environment, climate and energy. Do these findings provide a reasonable general picture of the most important challenges for the next decade?
- Identification of technological fields and trends in the open literature has been used as an indicator for the future need for technological service. Is this a reasonable approach?

The experts were selected in consultation with the Agency for Science, Technology and Innovation and the GTS Secretariat.

7.3.1 Leo Larsen

Leo Larsen is the president and CEO of Sund & Bælt Holding A/S. Other directorship positions he holds are chairman of the Copenhagen Energy board of directors, chairman of the Coordination Unit for Research in Climate Change Adaptation at the Ministry of Climate and Energy, co-chairman of the RenHold A/S board of directors, member of the Renoflex A/S board of directors, and chairman of the National Food Forum under the Ministry of Science, Technology and Innovation.

The interview was performed on 19 January 2009. The following is an outline of the main viewpoints expressed in the interview, and it has been approved by Mr Larsen.

Identified technological fields and trends

The list of identified technological and sectoral fields and trends from the reviewed foresight studies seems to provide a complete and comprehensive picture of technological developments. From a general perspective, no significant fields and trends were overlooked.

Compliance between the foresight studies reviewed and GTS2015

There is good compliance between the fields and trends identified in the studies reviewed and the technological focus areas and trends presented in GTS2015. It is interesting that the review and comparison exercise indicate relatively few areas given a high degree of attention and significance (energy, environment, climate, energy and ICT).

Main challenges: Health, environment, climate and energy

The key challenges of health, environment, climate and energy identified can be characterised as transdisciplinary in the sense that solutions will have to be developed across disciplines, institutions and actors. One example is that health-related issues interface with nutrition, food and climate-related issues. Another example is that nearly all business and public sectors have an impact on climate and climate-related issues, and so their solutions require cooperation between several scientific and social disciplines.

The picture from the review and comparison indicates that issues related to ‘societal demand pull’ are higher on the agenda than issues related to ‘technology or industrial pull’. This picture seems right and meaningful. In this connection, it important to stress that contributions from hardcore technologies will only to a minor extent be sufficient to find sustainable solutions to the challenges. A cross-disciplinary approach that includes social competencies as well as those in the humanities is greatly needed if socially acceptable solutions are to be reached. Too often, technological innovation processes lack a cross-disciplinary perspective and approach, especially in the early stages of the innovation process. It is definitely not sufficient to treat social understandings as add-ons to technological projects. For example, the development of a sustainable transport infrastructure system and changes in behavioural traffic and transport patterns are needed just as much as new and improved technologies.

Technology foresight

There was room for improvement in the first generation of technological foresight studies. The second generation is of a much higher scientific quality and usable for various purposes related to research prioritisation and the identification of future needs. It is difficult to suggest another and more appropriate approach to the identification, discussion and evaluation of future challenges and possibilities. On the other hand, it must be noted that foresight practitioners have a tendency to refer to each others' work and reports, thus blurring the origin of their statements and perhaps also losing the original thinking.

Cultural and value trends

Compared to today, factors and aspects related to our understanding of culture and values require much more attention and awareness. Cultural factors must be considered just as important as technological factors and must to be integrated into all stages of innovation processes. It is of the utmost importance to gain a deep understanding of the influence of cultural behaviour as regards the future demand for products and services. Also, globalisation and increased international cooperation will call for people capable of understanding and handling intercultural situations and collaboration.

Other comments

To some extent, both GTS2015 and the studies reviewed express mainstream thinking and a lack of original self-contained thinking. It is necessary also to ask for a more radical and challenging way of thinking. One example is the ideas formulated in the concept of a knowledge-based bio-economy, which is a new way of thinking about products and the economy. In a long term perspective, the prediction is that an economy based on sustainable and biological resources will replace the economy of today, which as we know is based on resources such as minerals, metals and fossil fuels.

7.3.2 Professor Frede Blaabjerg

Dr Frede Blaabjerg is professor and dean at the Faculty of Engineering, Science and Medicine at Aalborg University. He served as a member of the Danish Technical Research Council in Denmark in 1997-2003 and as its chairman in 2001-2003. He was also chairman of the Danish Small Satellite Programme and of the Center Contract Committee, which supports collaboration between universities and industry. He became a member of the Danish Academy of Technical Science in 2001, and in 2003 he joined the academic council. In 2002-2003 he was a member of the Board of the Danish Research Councils and in 2004-2006 chairman of the Energy and Environment programme committee. He became a member of the board of the Danish High Technology Foundation in 2007. He is an expert member of ERC and the EU programme committee for energy. He has also been a member of the board of the Danish Strategic Research Council since 2008.

The interview was performed on 21 January 2009. The following is an outline of the main viewpoints expressed in the interview, and it has been approved by Professor Blaabjerg.

Identified technological fields and trends

The fields and trends identified from the foresight studies can be considered mainstream thinking and in accordance with themes highlighted and discussed in various scientific communities and commissions, both national and international.

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Compliance between the foresight studies reviewed and GTS2015

There is good compliance between the fields and trends identified in the foresight studies reviewed and the technological focus areas and trends presented in GTS2015.

Main challenges: Health, environment, climate and energy

The picture that the review and comparison form indicates that issues related to 'societal demand pull' are higher on the agenda than issues related to 'technology or industrial pull'. For the time being, this seems right and meaningful. Public concerns and awareness on issues such as health, environment, climate and energy are significant and high on the agenda in the media. Together with an increasing unemployment rate, these issues will lead to societal demands and pressure on many products and services. There will also be requests for common solutions that fulfil the needs and requirements of broader groups in society. Technology pull will most likely have less strength and impact in the near future.

Technology foresight

Technology foresight processes can be productive for the participants in the working process. Often, unfortunately, foresight studies and their recommendations are quickly out of mind unless there are funding opportunities closely connected to the themes of the foresight studies. On the other hand, it is important to continuously challenge priorities and thinking in society, so foresight studies and the processes behind them are valuable. There will always be a need for future thinking, but we have to rethink the organization of the processes to increase the impact of such studies. Technology foresight studies themselves are not being used as an instrument or tool by the research councils in Denmark.

Cultural and value trends

The complexity of modern society and modern life is close to the limits of what we as human beings are able to adapt to. There will be a reverse trend towards and debate about simple living, with the argument that more work and tangible goods are not the basic meaning of life. Life is not just a question of increased growth. Issues related to stress factors will gain more and more attention as well.

As regards international cooperation, there will be an increasing focus on and demand for building intercultural competence and skills.

Other comments

Three issues are of basic importance for human life: water, food and energy. Water and food are needed to survive, and energy is needed for mobility in modern society. Themes and aspects related to clean water and water resources hold a prominent position neither in the review nor in GTS2015, but they ought to be given high priority.

An important megatrend to be mentioned is urbanisation and the movement from rural areas to megacities with 30-40 million inhabitants. A future challenge will be the construction and organization of infrastructure and supply systems for these megacities. Denmark has experienced and highly qualified consultants in the fields of environment, construction, architecture, design, etc.

For the GTS system, a major challenge in the future will be to position itself with respect to universities and consultants. Danish universities are under pressure to collaborate more with the business enterprises and public-sector organizations, and they could be a strong and powerful competitor to the GTS system. One recommendation for the GTS institutions is to establish close partnerships with the universities in order to ensure that the role of GTS institutions is different from the role of universities.

8. Summary and recommendations

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Approach in the review

Our review was performed by scanning selected studies in the open literature: four international studies, three national-level studies and ten Danish-specific technological foresight studies. The studies were conducted between 2002 and 2008. Each foresight study was presented here in the form of a short summary: obviously, a great deal of detailed information has been left out.

The studies were selected to cover both international and national aspects and trends. It must be noted, however, that the studies included constitute a small fraction of all the foresight and futures studies conducted at that time.

The selected foresight studies were reviewed with a view to determining the technological fields and development trends treated. The technological fields thus identified were then organized into thematic classes related to 'technology and industrial push' and 'social demand pull', and the identified trends were structured using the STEEPV approach (social, technology, economics, ecology, politics and values). Other structuring principles could have been chosen.

Approach in comparing the review with GTS2015

The foresight studies reviewed and the GTS2015 represent a huge variety of methodological approaches and principles. This variety creates dilemmas and difficulties in a comparison, e.g. how to take a study structured with technological fields as the leading principle and compare it with a study having societal development needs as the leading principle.

In this report, we compared the studies reviewed with GTS2015 from three different starting points:

i) the GTS2015 focus areas were taken one by one and briefly compared with the observations of the review,
ii) the GTS2015 technological focus areas were compared with the technological fields identified in the studies reviewed, at a high level of aggregation, and
iii) the GTS2015 trends were compared with the trends identified in the studies reviewed, also at a high level of aggregation.

Main findings and recommendations

The aims of the study were (a) to sketch images of the future need and demand for technological services in Denmark based on generic technological domains and development trends, (b) to identify uncertain and significant drivers of change with an impact on the need and demand for technological services in Denmark, and (c) to inspire and support discussion of and reflection on plausible development paths for technological services in Denmark within a time horizon of ten years.

The picture of future needs and trends gained from our study indicate that strategic issues and public-function issues related to 'societal demand pull' are higher on the agenda than issues related to 'technology or industrial pull'. The technological fields most often mentioned in the foresight studies were ecology, energy, climate, health and ICT, and the trends most often mentioned were ecology, ageing society, innovation and knowledge society.

Trends related to culture, values and the experience economy have more attention in the foresight studies reviewed than in GTS2015. This difference may indicate uncertain drivers with respect to GTS but also drivers that may have a direct and significant influence on the direction of future developments. The two experts interviewed expressed the viewpoint that factors and aspects related to understanding culture and values require much more attention and awareness than they are receiving today.

- *GTS organizations should thus consider non-technical issues such as the aging society, the knowledge society, and understanding cultures and values in the future development of their organizations.*

In general, there is good compliance between issues mentioned in the foresight studies reviewed and in GTS2015. Obviously, the entire pool of foresight studies covers more and other issues than the GTS2015: the studies were conducted on the basis of other incentives, aims and resource allocations than GTS2015 was. It must be stressed that review and comparison with such a high level of aggregation as ours does not directly indicate Danish niches and strength positions.

- *Thus GTS organisations should individually consider making a more detailed analysis of the Danish industrial niches and strength positions in relation to their specific areas of competence.*

With reference to the interviews, two aspects related to development paths for technological services can be singled out. First, a major future challenge for the GTS institutions will be their positioning themselves in relation to universities and consultants. Especially the current consolidation and merger process occurring among universities and technology research centres in many European countries (including tighter cross-border collaboration) might challenge the GTS organizations.

- *Thus GTS organizations should rethink their role in relation to universities and rethink how to distinguish themselves more clearly from the emerging new role of the universities.*

Second, both the studies reviewed and GTS2015 express to some extent mainstream thinking and a lack of original self-contained thinking.

- *Thus GTS organizations – either jointly or individually – should expose themselves to a more challenging way of thinking and consider making more radical changes.*

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10. Enclosure A: The Eighth Japanese Delphi – top five topics in particular areas

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Year T: Time of technological realization; **Year S**: Time of social application.

Information and communications fields

Top five topics in degree of importance to Japan (NISTEP, 2005, p99).

Topics	Area	Year T	Year S
A highly reliable network system capable of protecting the privacy and secrecy of individuals and groups from intrusion by malicious hackers.	Information security	2012	2016
Generalized technology extended from total building management systems and home security systems, which is coupled with seismic detection systems so that the safety of human life can be ensured before seismic waves arrive, in an earthquake whose epicenter is distant.	Information security	2012	2020
Technology to detect intrusions and viruses on the Internet backbone.	Information security	2009	2013
Capability of tracing back the source address of suspect packet in the Internet to detect intrusions.	Information security	2009	2013
Forecasts of diseases and disasters through advanced modelling and simulation technologies for large-scale ecological, environmental, or other systems.	High-productivity computing	2015	2023

Electronics

Top five topics in degree of importance to Japan (NISTEP, 2005, p143).

Topics	Area	Year T	Year S
A crustal movement sensor that enables prediction of an earthquake a few minutes before it occurs.	Security electronics	2015	2023
A small-scale semiconductor fabrication plant that supports high-mix, low-volume production and allows a two-orders-of-magnitude reduction in capital investment from current levels.	Silicon electronics	2013	2019
Almost all indoor lighting is replaced by semiconductor light sources.	Optical and photonic devices	2012	2018
A 100M-gate LSI whose logical function changes in real time.	Silicon electronics	2013	2021
Widespread home use of 10-Gbps access networks.	Optical and photonic devices	2012	2017

Life science

Top five topics in degree of importance to Japan (NISTEP, 2005, p192).

Topics	Area	Year T	Year S
Effective technology to prevent cancer metastasis.	Basic research for new medical technologies	2020	2030
Technology for immediate complete control of allergies based on elucidation of the immunoregulatory mechanisms and environmental factors that lead to hay fever, atopic dermatitis, and other allergies.	Basic research for new medical technologies	2015	2027
Treatment for preventing the progression of Alzheimer's disease.	Understanding and treating brain conditions	2019	2030
Elucidation of the etiology of manic-depressive psychosis at the molecular level.	Understanding and treating brain conditions	2020	-
Technology to detect a cancerous tissue of the diameter smaller than 1 mm presenting anywhere in the body.	Monitoring and sensor technology for biological substances	2014	2023

Health, medical care and welfare

Top five topics in degree of importance to Japan (NISTEP, 2005, p228).

Topics	Area	Year T	Year S
Elucidation of the pathogenesis of atherosclerosis.	Personalized medicine	2015	-
Therapeutic application of the achievements on the pathophysiology of cancerization.	Personalized medicine	2021	2028
Elucidation of the pathophysiology of cancer metastasis.	Personalized medicine	2018	-
Prophylactic technologies to overcome hospital-acquired infection.	Elucidation of biological defence mechanisms and therapeutic application	2011	2018
Methods to overcome drug resistance in infections.	Measures against emerging and re-emerging infectious diseases	2014	2022

Agriculture, forestry, fisheries and food

Top five topics in degree of importance to Japan (NISTEP, 2005, p268).

Topics	Area	Year T	Year S
Risk management technology for harmful chemicals (endocrine disruptors, heavy metals, etc.) based on elucidation of their long-term impact on human beings, crops, livestock, and ecosystems.	Development of a food system for a safe, peaceful, long-lived, and healthy society and other new technologies for daily life	2015	2024
Formation of positive understanding and consensus on genetically engineered plants and foods.	Development of a food system for a safe, peaceful, long-lived, and healthy society and other new technologies for daily life	-	2015
Prevention, diagnosis, and treatment technology through the complete elucidation of BSE onset.	Development of a food system for a safe, peaceful, long-lived, and healthy society and other new technologies for daily life	2013	2020
Achievement of low-cost agriculture and forestry and rural communities oriented towards zero emissions by using local agricultural and forestry resources, organic waste, and other sources of biomass energy.	Biological solutions to environmental problems and achievement of a sustainable society	2014	2022
Technology to estimate long-term changes in resource amounts in order to appropriately manage true sardines and other important fisheries resources.	Elucidation of the complex interaction between biodiversity and ecosystems	2015	2022

Frontier

Top five topics in degree of importance to Japan (NISTEP, 2005, p296)

Topics	Area	Year T	Year S
A risk management system that utilizes disaster observation satellites, communications satellites, GPS, unmanned aircraft, etc. to observe disasters, understand situations after disasters occur, and respond swiftly (send the necessary information where it is needed).	Space, ocean, and Earth technology for a safe and secure society	2009	2014
Technology to forecast the timing and scale of volcanic eruptions by observing and assessing in real time magma conditions inside volcanoes that are likely to erupt.	Space, ocean, and Earth technology for a safe and secure society	2014	2022
Technology to precisely forecast the imminence (place and time period) of earthquakes (plate boundary earthquakes and inland earthquakes) of magnitude 7 or greater that are likely to cause damage, helping mitigate human disasters.	Space, ocean, and Earth technology for a safe and secure society	2021	2030

Technology to evenly and densely place comprehensive earthquake/ crust change observation equipment in major cities, mountainous areas, continental shelves, etc. in order to predict earthquakes.	Space, ocean, and Earth technology for a safe and secure society	2010	2016
Formation of a worldwide consensus, including developing countries, on international regulations on the output of carbon dioxide and other greenhouse gases.	Space, ocean, and Earth technology for a safe and secure society	-	2014

Energy and resources

Top five topics in degree of importance to Japan (NISTEP, 2005, p340).

Topics	Area	Year T	Year S
Geologic disposal technology for high-level radioactive waste.	Innovative nuclear power systems	2020	2032
Recycling systems for the production, distribution and consumption of recovered materials and products based on new economic criteria/ standards.	Recycling system (including biomass and waste)	-	2016
Technology for electric power generation and synthetic fuels manufacturing using the gasification of coal, biomass and waste.	Clean-coal technology;	2010	2018
Polymer electrolyte fuel cells for automobile use.	Fuel cells	2012	2020
Hydrogen supply infrastructure networks for fuel cell automobiles.	Hydrogen energy systems	2013	2023

Environment

Top five topics in degree of importance to Japan (NISTEP, 2005, p373).

Topics	Area	Year T	Year S
Technology for forecasting abnormal weather disasters resulting from climate change.	Environmental disasters	2015	2023
Technology for predicting and assessing global depletion of the resources that are used in Japan.	Environmental economic index	2012	2018
Energy consumption per capita in Japan is cut in half.	Lifestyle based on environment	-	2031
Technology for minimizing the impact of and restoring damage from large-scale industrial accidents.	Environmental disasters	2012	2017
Introduction of an automobile tax based on CO_2 emissions.	Lifestyle based on environment	-	2013

Nanotechnology and materials

Top five topics in degree of importance to Japan (NISTEP, 205, p407).

Topics	Area	Year T	Year S
Production processing technology capable of controlling dimensions and shapes with single nanometer precision.	Nano processing, molding, and manufacturing technology	2013	2019
Large-area amorphous silicon solar cells with a conversion efficiency above 20 percent.	New materials from nanolevel structure control	2012	2020
Hydrogen production processes through photocatalytic decomposition of water with sunlight.	Environment and energy materials	2013	2022
Biochip diagnostic systems that can accurately diagnose onset risk for cancer and other serious diseases and supply information for setting treatment within a very short time.	Nanobiology	2012	2020
Three-dimensional packing technology at the nanometer scale.	Nanoprocessing, -molding, and -manufacturing technology	2013	2020

‘Manufacturing

Top 5 topics in degree of importance to Japan (NISTEP, 2005, p446)

Topics	Area	Year T	Year S
Widespread use of production processes using low CO_2 emitting energy sources such as non-fossil energy (wind, geothermal, photovoltaic, solar heat, waste heat, etc.), cogeneration systems, stationary fuel-cell systems etc.	Recycling-oriented manufacturing technology with a low environmental load	2014	2023
Implementation of a new elementary and secondary education scheme that emphasizes science and mathematics to make Japan a world leader in science and technology.	Questions regarding other topics	-	2013
A technical education program that ensures the handing down of expertise and craftsmanship by establishing technology for converting implicit knowledge on manufacturing and manufacturing technique (e.g. basic techniques and skills, know-how, experience) into explicit knowledge.	Questions regarding other topics	2013	2019
Promotion of human resources mobility that is promoted across industry, academia, and government, leading to a greater number of joint or collaboration projects, and consequently bringing about innovations in manufacturing technology.	Questions regarding other topics	-	2013
Manufacturers' responsibility for collecting and disposing of discarded products is defined by law, and recycling systems in which more than 90% of used material is thermal- or material-recycled become widespread. Design for recycle/disassemble technology, easy assemble & disassemble production technology , selective collection system technology etc. enable it to achieve.	Recycling-oriented manufacturing technology with a low environmental load	2013	2021

Industrial infrastructure

Top five topics in degree of importance to Japan (NISTEP, 2005, p483).

Topics	Area	Year T	Year S
A social environment that encourages women to balance work and marriage, childbearing, and childrearing (e.g. 30% of listed companies set up day care centres) becomes a reality in Japan to promote the utilization of female human resources.	Human resources management	-	2014

In Japan, for easier job changes, corporate pensions become 'portable' so that the pension funds deposited under the pension programme of the previous employer can be transferred to the new employer's pension programne when a worker changes jobs.	Human resources management	-	2013
Over half of Japan's listed companies adopt management schemes that emphasize corporate social responsibility as the fundamental business policy.	Environmental management	-	2011
Facilitation of international business operations based on international standards, as a result of international standardization of the laws governing commercial activities, transactions, taxing, competition, and intellectual property rights in the international context.	Optimization of industrial infrastructure through regional dispersion and concentration	-	2016
Reeducation/retraining programmes for "capacity building among the existing workforce," or for improving specialized skills and productivity among part-time and temporary workers are widely implemented in Japan.	Human resources management	-	2013

Social infrastructure

Top five topics in degree of importance to Japan (NISTEP, 2005, p518).

Topics	Area	Year T	Year S
Technology for safely and efficiently demolishing and removing commercial nuclear power plants after decommissioning.	Revitalization, maintenance, and management of social infrastructure	2013	2020
High-accuracy rainfall prediction technology capable of providing reliable forecast information on floods and landslides.	Disaster prevention technology	2012	2019
A disaster prevention system in which the occurrence of an earthquake is reported through a nation-wide earthquake detection network to the areas more than 50 km away from the epicenter before the seismic waves reach there.	Disaster prevention technology	2008	2013
Technology for medium-term (5-10 year) prediction of major earthquakes (magnitude 8 or greater) by the analysis of crustal strain distribution and the records of past earthquakes.	Disaster prevention technology	2013	2021
Technology for recycling, rather than demolishing, deteriorated infrastructure and technology for maintaining and managing infrastructure to extend its life.	Revitalization, maintenance, and management of social infrastructure	2012	2019

Social technology

Top five topics in degree of importance to Japan (NISTEP, 2005, p571).

Topics	Area	Year T	Year S
A wide-area disaster monitoring system that, when a major disaster occurs, monitors the impacts of the disaster widely across the affected area, by using satellite images and analysis by laser radar equipment to help provide prompt and safe evacuation guidance.	Urban safety, security, and stability	2011	2018
A system for quickly and accurately detecting trace amounts of explosives, drugs, radioactive substances, and pathogenic microorganisms in public and other crowd-attracting facilities and public transportation such as airports, seaports, and railroads.	Urban safety, security, and stability	2013	2020
Systems for early warning and prediction by experts (e.g. early detection of human/livestock infection and prediction of its impacts, early warning of the environmental effects of an accident or disaster) are established, enabling early detection and impact assessment of the problems that should be solved by science and technology.	Technology assessment	2013	2021
A system that supports women's social participation by ensuring mothers the future availability of child-rearing support such as nursery schools, at the time of pregnancy or childbirth.	Universal availability of services	-	2012
A system that prevents senile dementia by inhibiting impairment of an elderly person's brain function.	Social application of brain research	2015	2022

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