DANISH MINISTRY OF THE ENVIRONMENT

Environmental Protection Agency

Green Technology Foresight about environmentally friendly products and materials

- The challenges from nanotechnology, biotechnology and ICT

Michael Søgaard Jørgensen[1], Maj Munch Andersen[2], Annegrethe Hansen[1], Henrik Wenzel[3], Thomas Thoning Pedersen[1], Ulrik Jørgensen[1], Morten Falch[4], Birgitte Rasmussen[2], Stig Irving Olsen[3] and Ole Willum[3].

[1]Department of Manufacturing Engineering and Management, Technical University of Denmark,
[2]Systems Analysis Department, Risoe National Laboratory,
[3]Institute of Product Development
[4]Center for Information and Communication Technologies, Technical University of Denmark.

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Preface

The focus of this green foresight project is the future environmental challenges and possible environmentally related competitive advantages related to the three generic technologies (or technology areas) nanotechnology, biotechnology and ICT (information and communications technologies). Focus has been on aspects of environment and health in general and particularly chemical aspects. The aim has been to develop recommendations for integrated environmental and innovation policies in Denmark and the EU in relation to the three technology areas in order to reduce and prevent the future impacts on environment and health, ensure focus on the environmental potentials in research, innovation and applications, and obtain environmentally related competitive advantages.

The project has been financed by the Danish Program for cleaner Products and has run 2004-2005. Department of Manufacturing Engineering and Management at Technical University of Denmark (DTU) and the System Analysis Department at Risoe National Laboratory have been responsible for the project together with Institute for Product Development. Center for Information and Communications Technology (CICT) at DTU has contributed to the project.

Part of the background for the project was a recommendation of the Green Technology Foresight project co-ordinated by the Danish Ministry for Science, Technology and Innovation 2002-2003 about a combined environmental and innovation strategy and a focus on green products and materials. Also EU's Environmental Technologies Action Plan (ETAP) (see for example (Commission of the European Communities 2003) includes visions with regard to integration of innovation and environmental considerations. As part of the analysis of the policy processes in the EU the project co-operated with The Institute of European Environmental Policy (London and Brussels) on EU's Environmental Technologies Action Plan – ETAP.

Interviews and meetings with researchers, companies, consultants, governmental authorities and environmental organisations and three workshops on plastics, on intelligent products and processes, and on policy, respectively, have contributed to valuable dialogue and knowledge in the foresight project. In connection to the project the European Environmental Agency and the Danish Ministry of Environment organised an international High Level Conference in Copenhagen, 19-20 April 2005: "Eco-innovation: Potentials and challenges of tomorrow's technologies. Perspectives for business, Europe and the environment". A draft of the report was presented at the conference. Also this conference has contributed to the dialogue and the knowledge building in the project. There has also been co-operation with the nanotechnology foresight, carried out within the Danish Ministry for Science, Technology and Innovation in 2004.

Summary and recommendations

The objectives of the project

The objectives of the Green Technology Foresight project have been:

- to analyse the environmental potentials and risks in general and in relation to chemicals in particular, related to the three technology areas within the coming 15 – 20 years,
- to identify areas, where Denmark has or could have environmental competitive competencies within environmentally sound design of products and materials;
- to analyse how environmentally promising innovation paths might be supported in Denmark and in the EU, and develop policy recommendations for integrated environmental and innovation efforts.

Recommendations integrating future environmental and innovative aspects of ICT-, bio- and nanotechnology

The development within the three technology areas hitherto and the identified probable future trends introduce issues concerning environmental potentials and risks, including potentials and risks related to use, wastes and emissions of hazardous substances and materials. The following recommendations aim at high quality environmental governance in the development of the three areas, so that issues of societal needs and environmental potentials and risks are addressed within planning and management of research, innovation and technology applications.

The developed recommendations are structured within the headlines

A. Environmental governance

B. Guiding research and research policy

C. Policy support for eco-innovation

D. Regulating application areas

The recommendations suggest roles to a broad variety of stakeholders, like research and innovation institutions, businesses and business organisations, governmental authorities, and consumer and environmental non-governmental organisations. The Ministry of Environment and Ministry of Science, Technology and Innovation are seen as important governmental authorities in the planning of the implementation of the recommendations.

A. Environmental governance

Strengthen the environmental governance in relation to ICT-, bio- and nanotechnology

General proposals:

A1. Strengthened environmental governance should aim at

- focus on environmental potentials and risks in research, innovation and applications related to the three technology areas
- high legitimacy of the societal problems and needs and the environmental potentials and risks addressed in research and innovation
- critical comparisons of environmental potentials and risks of the three areas with other environmental strategies

A2. Strengthened environmental governance calls upon

- more, high quality participation of concerned and affected stakeholders in the planning, management and assessment of public and private research and innovation activities related to the three technology areas
- changes in the procedures in planning, management and assessment of public and private research and innovation to make this participation influential
- facilitation of dialogue between different types of knowledge and experience (environmental, ethical, technology etc.)

Economic support is needed for Danish researchers', governmental authorities', and NGO's continued national and international networking around experiences with environmental governance in relation to the three technology areas.

A3. Supplementary proposals concerning environmental governance within the three technology areas:

ICT:
There is a need for continued discussions about the environmental aspects of ICT and how they are shaped in interaction with societal trends like globalisation, more intense everyday life etc. This is also important as ICT technology in the future might get embedded into many new products like textiles etc. Such discussions should enable analyses that get deeper than the metaphor of 'the knowledge society' as very knowledgeable and only having limited resource consumption.

Biotechnology:
There is need for more public participation in the shaping of the future research and innovation strategies for white biotechnology. This should ensure discussions that get deeper than the metaphor of white biotechnology as a 'clean technology' in itself, because it is based on biological materials and processes.

Nanotechnology:
There are rising public, governmental and scientific concerns about how nanotechnology may lead to new types of health and environment risks because of new types of materials and processes with new characteristics. Environmental risks have hitherto been neglected to a high degree in the nano community. Since nanotechnologies could undergo much change the next 5-

10 years there is need for ongoing dialogues highlighting trends, visions and fears. Nanotechnology comprises many different scientific fields why there is a need for discussions focusing on the different types of nanotechnology.

B. Guiding research and research policy:

Stronger integration of environmental aspects in the guidance of research and research policy

General proposals:

B1. It is suggested to develop

- Broad and strong stakeholder participation (e.g. through new think tanks) in the ongoing development and assessment of visions for the environmental focus (potentials and risks) in research related to ICT-, bio- and nanotechnology
- Strengthened dialogue between the Ministry of Environment and the Ministry of Science, Technology and Innovation about strategies for focus on environmental potentials and risks in the research programmes of the Ministry of Science, Technology and Innovation
- Use of Constructive Technology Assessment and Green Technology Foresight, including participatory and dialogue-based processes as tools in future research planning and research assessment in relation to ICT-, bio- and nanotechnology
- Development of funding strategies for research in environmental aspects of the three technology areas. The strategies should consider dedicated funding for technology assessment and technology foresight and for environmental research (potentials and risks), and integration of environmental aspects into technology research, both in relation to mature and new fields
- Development of strategies for independent assessment of environmental potentials and risks in research proposals
- Development of strategies for integration of environmental competence in technology research, combining development of environmental competence in technology research groups and development of independent environmental research capacity based on competencies within environmental science, engineering and sociology of technology

B2. Supplementary proposals for guiding research and research policy within the three technology areas:

ICT:
There is need for more knowledge about the role of ICT-based tools and technologies in the shaping of eco-efficient use patterns and in environmental management in order to develop more socio-technically based development strategies and paradigms for ICT-technologies. This includes:

- Research on the interaction between intelligent products, users and organisational and societal context in the development of use patterns and the environmental aspects hereof
- Research on the role of ICT-based tools in the development of environmental competence in businesses etc. in order to develop

strategies for effective development and application of such tools as part of environmental management

Biotechnology:
More knowledge about the environmental aspects of biotechnology seems to be one of the prerequisites for future application of these technologies. This includes:

- Research on the environmental potentials and risks of bio-remediation of pollutants based on release of genetic modified microorganisms
- Research on the environmental risks related to release from chemical-producing plants
- Research on the health impacts of an enhanced use of enzymes

Nanotechnology:
The key barrier to nano eco-innovation is the lacking awareness and knowledge of nano-related eco-potentials and business potentials. It is difficult to get environmental funding for fundamental nano research, since this kind of funding tends to focus on more mature and immediate solutions. There is need for:

- A nano eco-innovation research programme and/or a technology platform based on the identified eleven nano research areas with eco-potentials
- Research on the environmental impacts of all kinds of nanotechnology, particularly the toxicity of nanoparticles and other nano materials, including development of the capacity to absorb and mediate similar research from abroad
- Further development of existing environmental assessment procedures which are not adequate for measuring and handling materials at the nano scale and build nano competencies in the institutions undertaking these.

C. Support for eco-innovation

Support eco-innovation based on pre-commercial technologies with environmental potentials

<u>General proposals:</u>

C1. Support for eco-innovation should be organised through

- Strengthened dialogue between the Ministry of Environment and the Ministry of Science, Technology and Innovation about strategies for ensuring focus on environmental potentials and risks in the innovation programmes of Ministry of Science, Technology and Innovation, including the Danish High Technology Foundation and the Innovation Consortia tool
- Development of environmental and economic visions and targets for specific technology areas
- Support for development of prototypes and for demonstration projects

- Market development through development of standards and long-term environmental regulation of related chemicals, resources, competing technologies etc.
- Support for development of eco-innovation-oriented competence in research and innovation through integration of environmental competence and technology competence

C2. Launch a Danish Green Innovation programme focused on key environmental themes and key product and consumption areas

- The programme should be based on a combination of measures directed towards research, innovation, potential application areas and governance.
- Competencies within eco-innovation, environmental assessment and consumption dynamics should be included.
- The planning of the programme should be based on dialogue among government, research and innovation institutions, business, and consumer and environmental organisations.

C3. Strengthen the role of environmental concerns in the further development of ETAP

The Danish government should encourage and support

- A stronger link between the focus of the ETAP technology platforms and important environmental themes
- Inclusion of a broad variety of environmental regulation instruments as measures in the ETAP implementation
- Participation of consumer and environmental organisations in the development, planning and management of the technology platforms in order to develop their environmental scope
- Danish participation in and initiatives for technology platforms related to ICT, biotechnology, nanotechnology and chemistry

C4. Supplementary proposals for eco-innovation within the three technology areas:

ICT:
There is a need for more focus on the potentials and limits to intelligent products and applications and sensors as elements in an eco-efficiency strategy. Furthermore, there is a need for strategies to ensure focus on hazardous substances and materials and radiation in the development of products and components:

- Support for innovation in intelligent products and applications, including pervasive computing, with focus on the interaction between ICT-based products, users and societal and organisational context in order to develop concepts and paradigms for eco-efficient use patterns
- Analysis of the perspectives in further development of sensors for environmentally oriented process regulation and control, including

different types of governmental regulation, which can support the development and dissemination hereof

- Development of strategies for effective enforcement of the RoHS directive for electronic products and components for the domestic market, for export markets, and for imported products
- Development of demands to the radiation from electronic equipment and components, and from wireless communication. Ongoing assessment of the amount and kind of radiation in homes, workplaces, schools and the public space

Biotechnology:
There is a need for development of enzymes with eco-potentials for a broader variety of industrial processes. Furthermore, there is also a need for a strategy for the use of bio-mass as renewable resource:

- Encouraging development of enzymes for a broader variety of industrial processes through dialogue between potential manufacturers and users
- Development of short-term and long-term national strategy for the use of different types of bio-mass as renewable resource for chemicals, energy, materials etc.

Nanotechnology:
There is a need for considerations about how the industrial up-take of nanoscience can be promoted, through existing industry and through new start-ups. A central barrier is lacking environmental competencies in the Danish nano community and lacking nano competencies among environmental experts and industry and the weak linkages between these groups:

- A national think tank or environmental nano network should facilitate a take-off of a nano eco-innovation strategy
- Build environmental competencies in the nano research institutes or in connection to the new suggested and strengthened nano centres by employing or co-operating with environmental experts

D. Regulating application areas

Remove barriers to the dissemination of technology applications with environmental potentials

General proposal:

D1.Where mature and market introduced technologies with environmental potentials are not taken up by potential users, sector and product domain regulation should make present market, production and user regimes more environmentally oriented.

D2. Specific proposals for regulation of application areas in realation to the three technology areas:

ICT:

- Encouraging the use of ICT-based process regulation and control more towards higher eco-efficiency through stronger governmental regulation of wastes and emissions and prices on substances and materials, and support for environmental competence development in businesses and governmental institutions etc.

Biotechnology:

- Encouraging more widespread use of available types of enzymes in industry for increased process efficiency and substitution of chemicals through stronger demands to eco-efficiency and use of chemicals, and support for the necessary technological and organisational changes connected to the uptake, including the challenges faced by small and medium-sized businesses.

Nanotechnology:

- Regulation of application areas is not yet a key instrument for nanotechnology since most of the identified eco-potentials are pre-commercial, but it could become relevant later for specific product areas, e.g. for lighting or hydrogen cars.

Analysis and findings in relation to ICT

The term ICT (information and communications technology) is describing the tools and the processes to access, retrieve, store, organise, manipulate, produce, present and exchange data and information by electronic and other automated means. ICT is an umbrella term that includes any communication device or application, encompassing: radio, television, cellular phones, computer and network hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as videoconferencing and distance learning.

The aim of the research has been:

- To identify areas of ICT application that have been claimed to have or get environmental potentials and understand the shaping of these ICT applications as an interaction between the general dynamics of ICT, the dynamics of the application areas and the dynamics of the ICT applications within these areas
- To assess the environmental potentials and risks and the role of environmental concerns in research, innovation and governmental regulation related to these areas of ICT application

The analysis is based on desk research, interviews and workshops. The desk research has focused on former research and knowledge about the relationship between ICT and the environment in a wider perspective so the relation between ICT and the society has been a significant part of the desk research. The interviews have been carried out with actors from both Danish research environment and business using ICT as tool in their work. The actors have to a high degree been selected due to a relation to use of chemicals, materials or energy resources and not because of their specific interest and work with environmental issues.
The ICT research and development has in a high degree been left to the private business in Denmark, which in 2001 constituted 90 percent of the total research and development within the ICT-area. The ICT sector in

Denmark can be characterised by the following business and research related strengths:

- A strong position in the communications technology (including mobile, wireless and optical communication)
- A strong position internationally in global ICT/pervasive computing with competencies in embedment, system integration and user-oriented design
- Denmark is one of the leading countries regarding the use of ICT by the citizens, business and the public sector.

An important trend for more integrated and distributed software based services and less visible and smaller products and computer equipments will include some of the following developments:

- The disappearance of the computer
- Ubiquitous seamless connectivity
- Changing traffic patterns
- Disposable products
- Autonomous systems
- From content to packaging
- The emergence of virtual infrastructures

The relationship between ICT and the environment can be illustrated by ordering the impacts at three different levels. The first order relationships between ICT and the environment are the direct environmental impact from the ICT equipment and ICT infrastructure, i.e. the use of resources and the environmental impact from extraction of raw materials, manufacture, operation, and disposal of ICT equipment and infrastructure. The second order relationships between ICT and the environment are the environmental impacts related to the use of ICT in different applications. These relations are the most important concerning the potential substitution of processes stressing the environment, and improving the efficiency of production processes etc. The third order relationships between ICT and environment are the consequences of changes in the societies' total use of resources through changes in the magnitude of different business and product areas. This type of impact is represented in the possible parallel growth in e.g. the access to information and the consumption of material goods and transportation. This level of impact also includes social and structural changes in production and consumption resulting from the implementation of ICT almost everywhere.

Five application fields with relevance for environmental aspects have been analysed: a) Improving environmental knowledge, b) Design of products and processes, c) Process regulation and control, d) Intelligent products and applications and e) Transport, logistics and mobility
Some of the raw materials essential to modern electronics like copper, tin, silver, gold and platinum are based on scarce resources. Of the materials used in the manufacturing of ICT-equipment only two percent ends up in the product itself. The functionality of a number of typical ICT-product is continuously expanding, which implies means an increase in materials – and energy consumption.

There are potentials for environmental improvements from the use of ICT-based tools and devices for data collection and processing, information exchange, product and process design, and process regulation and control. More data processing capacity enables the processing of more data and more complex calculations. Some tools aim at more general resource efficiency. It is the aim of the application by the user that determines whether environmental achievements are in focus.

The integration of electronic components into products, so-called intelligent products or pervasive computing, shows environmental potentials related to automatic optimisation of the function of products, operational feedback to the user, digital product information about maintenance, reuse etc., integration of products into digital networks whereby use might take place during low load cycles of the electricity supply, and digital upgradeable products.

Telework, e-business and logistics are those ICT applications with the most implications for transport behaviour in the future. A limited amount of employees will be able to telework. Telework might imply that regular transport related to commuting and shopping in certain hours is replaced by more differentiated transport needs. This could challenge the existing infrastructure of public transport and strengthen individual transport solutions. Mobile telework will be more widespread as mobile communication solutions will offer the same facilities at comparable costs as those offered from the office. This may cause an increase in business travel transport due to the ongoing globalisation of manufacturing and trade. Within freight transport e-business could lead to more transport of small batches with high urgency to professional and private customers. The concept of just-in-time production in industry will also imply more transport due to the request for more frequent supply of small batches of materials and products. Logistic tools might optimise the amount of transportation within these organisational and economic conditions. The identified environmental potentials within the five areas of application play today no significant role in the development and use of software and ICT-equipment. Achievements within these fields demand environmental regulation of the respective application areas influencing the priorities made by the users and the dominant driving forces for innovations and implementations.

An increased amount of electronic products, miniaturisation of products and a more dispersed use of sensors and other devices could imply increasing problems in the future with electronic waste. Increased use of pervasive computing might cause health problems due to electro-smog and safety problems due to interference between different devices operating in wireless networks. Efficient implementation of the EU directive about hazardous substances in relation to electronic products could imply that some toxic materials are substituted in the future and the directive concerning waste could imply increased recycling of materials from the products.

Analysis and findings in relation to biotechnology

New biotechnology has, in addition to coming out in most, if not all, national foresights in the last 25-30 years as important for future techno-economic growth, also for the last 25-30 years been envisioned to have a number of environmental advantages, both with regard to remediation as well as to offering more sustainable production.

The aim of the research has been:

- To analyse how biotechnology and environmental perspectives have been conceived
- To analyse the future environmental potentials and risks within some areas of application for biotechnology, where environmental perspectives have been formulated
- To assess the role of environmental concerns in research, innovation and governmental regulation related to the areas of biotechnology application

From the 1990s and in the 2000s an increasing number of reports have specifically addressed the environmental perspectives in new biotechnology development, and in many cases addressed specific applications of new biotechnology. These envisioned applications have distinguished themselves from the pharmaceutical and medical applications of new biotechnology and from the application of new biotechnology in agriculture, and focussed on new biotechnology for industrial sustainability, monitoring and remediation. With background in these reports, the survey of new environmental biotechnology in Denmark has been delimited and focussed mainly on white biotechnology and on other areas, in which new biotechnology has been perceived as having environmental advantages, namely the areas of:

- enzyme production and application,
- fermentation efficiency,
- bio-polymers,
- bio-ethanol,
- biological base-chemicals, and
- bio-remediation

This delimitation means that only a part of the Danish biotechnology activities have been addressed. As the white biotechnology in general and in Denmark in particular is dominated by enzyme technology and the companies Novozymes A/S and Danisco A/S, the research and development within this area and these companies contributes largely to the foresight on white biotechnology.

The environmental performance of biotechnology is not an unambiguous issue. The mere fact that biological resources are degradable and of biological origin is not in itself an indication that biotechnology is environmentally superior to its alternatives. It is emphasized that any environmental assessment of a technology is a comparison to alternative pathways to provide the services in question, and that the alternative is most often is a well matured technology having had a long period of time to achieve its level of resource efficiency. This implies that up-coming technologies have to compete with matured ones, and often there has to be some kind of bottleneck to be broken for the up-coming alternative to be competitive. In the case of biotechnology, one such breaking of bottleneck is, of course, the genetic modification of micro-organisms implying huge efficiency increases of biotechnology, and there is no doubt what-so-ever that this will lead to the fact that bio-technology gains a lot of land from conventional chemical synthesis and products of petrochemical origin.

An essential characteristic of biotechnology is the heavy increase in process efficiency of fermentation. This leads in itself to benefits in terms of resource savings and related environmental impacts from the manufacturing and use of these resources. Moreover, it rapidly renders new application areas of fermentation products economically competitive to their conventional alternatives and allows for harvesting benefits related to using fermentation products in industrial and household processes worldwide.

In Denmark, enzyme technology comes out as a key technology for realisation of environmental benefits of biotechnology. It is demonstrated in the environmental assessments that enzymes in the referred cases address and reduce toxic agents, energy consumption and resource use, and references are made to representatives in the industry as well as researchers, who expect that enzymes will contribute even further by increased efficiency in production and use, by application within more industries and by further use in industries already using enzymes. Environmental aspects are referred to as potentially contributing to increase in the application of enzymes.

The majority of R&D in enzyme development is being carried out in industry. R&D in this area is referred to as having sprung from massive investments in biotechnology research and in molecular biology, and from R&D in pharmaceuticals and fermentation technology. The increasing applications of enzymes in industry is, in addition to large efficiency gains obtained in recent years, also to some extent a consequence of increasing focus on environmental problems and the regulation hereof. Examples are mentioned amongst other as the development of enzymes for ethanol production (which has also been supported with large R&D resources), the development of detergent enzymes to reduce amount and temperature of water, and the development of phytase for reducing the release of phosphorus from pig production. Development is further referred to as having benefited from the support of the introduced governmental regulation as well as of technological measures to reduce health and environmental risks, to meet the concerns of trade unions and environmental organisations.

With regard to developments within bio-ethanol and bio-polymers, environmental concerns have been key motivators, including concerns for fossil fuel scarcity. The environmental assessments of these areas of biotechnology, however, demonstrate a need for a more holistic evaluation of their perceived environmental advantages. Any use of biological resources may in the future have to address the fact that biological resources are of limited availability, and any environmental claim will, therefore, have to compare with alternative uses of such resources. Using arable land and agricultural crops for bio-ethanol and bio-polymers with the purpose of substituting fossil fuels, therefore, probably has to compare with using the same land and crops for substituting fossil fuels in the energy sector.

With regard to the application of new biotechnology to monitoring and remediation, it has been foreseen to contribute to cleaning of a number of pollutions. An important barrier for further research as well as development has been referred to as uncertainties regarding also the negative consequences. Private research and development primarily takes place in the US; however, further research into the potential positive and negative consequences still seem a prerequisite for a debate on the acceptability and extent of application.

Analysis and findings in relation to nanotechnology

Nanotechnology is an emerging general purpose technology, which by many is expected to form the basis of the next industrial revolution. It is high on the political agenda. The interest and funding going into this area globally in the later years is immense; also in Denmark. As yet, however, nanotechnology is at a very early, in many cases experimental stage of development. The actual potential of nanoscience turning into nanotechnology on a wide scale is still very uncertain and predictions and claims on the future development of nanotechnology must be treated very carefully.

The analysis of nanotechnology looks into:

- What is nanotechnology?
- What do international findings say on environmental opportunities and risks of nanotechnology?
- The path creation processes within nanotechnology in Denmark. Focus is on how environmental issues enter into the strategies and search processes of Danish nano researchers and related industry.
- The identification (mapping) of nano related environmental opportunities and risks as seen by Danish nano researchers.

The analysis concludes that in spite of frequent references to considerable eco-opportunities of nanotechnology in the general debate on nanotechnology, environmental issues are only moderately, in some cases quite weakly, part of the normal problem solving activity of the Danish nano technological community. Green attention and search rules are lacking. Consequently the nano technological paths which are currently in an early but critical phase of formation are not very green. This means that eco-opportunities are neglected and environmental risks are overlooked.

Quite a wide range of *potential* eco-opportunities are identified none the less, though much of this research is currently not directed towards environmental applications. The potential eco-opportunities are based on some intrinsic features of nanotechnologies which may facilitate eco-innovation. Much nanotechnology offers opportunities for resource efficiency gains e.g. through being small, efficient, lighter and more durable, but also more intelligent and tailored in the application. The analysis presents 11 main nano research areas and 39 specific research areas/nanotechnologies with eco-potentials as identified by Danish nano researchers. Six of these are expanded on in case studies. Many of the suggested eco-potentials may offer novel solutions to environmental problems. The potentials remedy environmental problems in four ways: a) ‘smart tailored’ products and b) new materials with new properties, which both could enable less use of energy and other resources in the manufacturing or the use of these products and materials, c) technology for more efficient energy systems and for energy systems based on alternatives to fossil fuel (fuel cells and solar cells) and d) environmental remediation with more targeted dosing of e.g. hazardous chemicals and more targeted treatment of pollutants.

The uncertainties as to the future development of these nanotechnologies are in many cases very uncertain. Also there is a lack of in-depth knowledge on both eco-opportunities and possible detrimental environmental effects.
There is a rising but new concern about environmental risks related to within the Danish nano community, similarly to the global trend. Competencies and concrete studies are lacking here though, particularly concerning not only the toxicity of nano materials but research into “clean nanotechnology”, including the environmental aspects of various stages in the product life cycle.
A series of barriers to obtain a stronger emphasis on environmental issues in nanotechnology development are identified, which policy should address.

Some of these are:

- Lacking environmental competencies in the Danish nano community and lacking nano competencies among environmental experts and policy makers.
- Lacking awareness of and belief in nano related eco-business opportunities (need of regulation to create new markets, need of demonstrations)
- Difficulty in getting environmental funding for fundamental nano research.
- Weak linkages between the nano community and the environmental researchers/experts and also the environmental industry.

The nanotechnology case raises important policy questions. Issues such as when and how to carry out dialogues and policy measures towards a technological field as nanotechnology whose technological materialisation in the near to medium future is highly uncertain and very diverse.

1 Introduction

1.1 The focus of the project

The objective of this project is to identify future environmental potentials and risks and study the possible environmentally based competitive advantages related to the three generic technologies[1]: nanotechnology, biotechnology and information and communications technology (ICT). The project is carried out as a green technology foresight on the selected generic technologies, which often are seen as future societal growth promoters in Denmark as in most other industrialized countries. Furthermore are green visions often highlighted in relation to the three areas. In the foresight process, the environmental and health potentials and risks of nano-, bio- and information and communications technologies are identified and assessed based on their present and possible future lifecycles from ‘cradle’ to ‘grave’, including production and use. The three technology areas have been selected by the Danish Environmental Protection Agency, reflecting the central role these technologies are given in both research and technology policy, but also reflecting the environmental potentials and risks, which often are highlighted.

The project focuses on aspects of environment and health in general and on consequences related to chemical aspects in particular. On this background the aim has been to make recommendations for integrated environmental and innovation policies in order to promote the environmental perspectives and to reduce future negative impacts on environment and health. The foresight focuses on Danish developments, but additionally draws on international developments with regard to environmental aspects and the dynamics of research, innovation and application.

1.2 The three generic technologies

As generic – meaning general purpose – technologies the societal impacts of the three selected technologies have the possibility to be profound. There are, however, quite large difference between the three technologies, when it comes to their degree of maturity and the amount of experience with their previous and present applications – differences of such importance, that they have to be accounted for and demands different approaches in the analysis. The differences may also serve as an inspiration for the analysis of the possible future innovation paths and environmental potentials by learning from the more mature technologies and their implementation.

The link between technological development and environment and health impacts are complex – especially in the case of such broad generic technologies as the ones studied. The impact on environment and health, including the chemical aspects, are in some cases directly linked to the technologies, but will in most cases be of an indirect nature linked through the combination with other technologies in the different areas of application and the driving forces shaping these applications.

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[1] The term general purpose technologies is often used, as well

In relation to ICT there are already quite some experiences with the impact of this technology as it already has been applied within many parts of society. Knowledge and practical experiences are available about the environmental aspects of ICT as shaped in interaction between the more general dynamics within ICT, the dynamics within the application areas of ICT and the dynamics of ICT application in consumption. While ICT is regarded as a technology that substitutes consumption of physical products with virtual products and thus is expected to reduce environmental impacts, the related growth in the use of ICT equipment and infrastructure may outperform the realized improvements.

Since the 1970'ies biotechnology has been predicted an industrial future within a number of areas, including chemical and pharmaceutical industry, food and beverage industry, energy production and agriculture, and as having both specific potentials in combating pollution as well as being capable of resource savings. Pharmaceutical applications have increased and constitute the major part of biotechnology development so far, which has been labelled the first phase of biotechnology applications. The use in modifying plants has been termed the second phase of (new) biotechnology, and these developments still face a number of uncertainties. Industrial or white biotechnology has been termed the third phase and has been envisioned to have the possibility of developing in the coming years, and to have the potentials of reducing the environmental impacts of a number of industrial processes.

Nanotechnology is the least mature of the three generic technologies and areas of study. Up till now only a few products based on nanotechnology and nanoscience have been introduced on the market. Nanotechnology has even not always been seen as a coherent scientific and technology area in itself, but more as a heading for a series of new interactions between chemistry, physics and biology. The expectations to the societal impact of this area of research and technology are largely due to the many possible fields of application, including the possibilities for producing stronger materials with new properties and reducing the physical dimensions of products and components.

1.3 The objectives of the project

The objectives of the Green Technology Foresight project have been:

- to analyze the environmental potentials and risks in general, and in relation to chemicals in particular, related to the three technological areas within the coming 15 – 20 years,
- to identify areas, where Denmark has competencies, which might contribute to enhanced competitiveness of Danish companies and position Denmark within environmentally sound design of products and materials;
- to analyze how environmentally promising innovation paths might be supported in Denmark and in the EU and develop policy recommendations for integrated environmental and innovation efforts.

On the background of the inertia in the existing knowledge, technological and industrial systems, the potentials for raising an environmental development agenda in these systems will be discussed. Drawing on these discussions, strategies and policy measures that may contribute to coherency in the environmental and innovation policy efforts will be pointed at.

1.4 Initiation and funding

The project has been financed by the Danish Environmental Protection Agency and has run 2004 - 2005. The Department of Manufacturing Engineering and Management (IPL) at the Technical University of Denmark (DTU) and the System Analysis Department at Risoe National Laboratory, together with the Institute of Product Development (IPU) have been responsible for the project.

The steering group of the project has consisted of Niels Henrik Mortensen, the Danish Environmental Protection Agency (chairman), Michael Søgaard Jørgensen, DTU and Maj Munch Andersen, Risoe.

The analysis on nanotechnology has been conducted by Maj Munch Andersen, Risoe with contributions from Birgitte Rasmussen, Risoe and Stig Irving Olsen, IPU and Marianne Strange, Risoe as consultant.

The analysis on biotechnology has been conducted by Annegrethe Hansen IPL DTU and Henrik Wenzel, IPU.

The analysis on ICT has been conducted by Michael Søgaard Jørgensen, Thomas Thoning Pedersen and Ulrik Jørgensen, IPL DTU, Morten Falch, CICT DTU and Ole Willum, IPU.

The project secretary has been Christine Molin, IPU.

Important target groups of the project are:

- The Danish Ministry of Environment and The Danish Ministry of Science, Technology and Innovation and related institutions in the EU;
- Design and innovation functions in companies;
- Consultants;
- Universities;
- Business, environmental and consumer organizations;
- The international research community within environmentally sound innovation processes and sustainable transition.

The project has been carried out concurrently with a number of other activities, focusing on the development of environmentally friendly materials and products. A combined environmental and innovation strategy and a focus on green products and materials were amongst other recommendations of the Green Technology Foresight project coordinated by the Danish Ministry for Science, Technology and Innovation 2002-2003. Also the nanotechnology foresight, carried out within the Danish Ministry for Science, Technology and Innovation in 2004, pointed to the importance of involving dialogues about the environmental aspects as part of the innovation activities. Finally the concurrent EU's Environmental Technologies Action Plan (ETAP) (see for example (Commission of the European Communities 2003) includes visions with regard to integration of innovation and environmental considerations.

1.5 Project activities

The main activities and outputs of the project have been as shown in the Table 1.1.

Table 1.1: Activities and outputs from the project.

Part 1: February-May 2004	Development of the green technology foresight concept and analytic framework Output: Methodology papers
Part 2: March-December 2004	Characterization of innovation paths related to nanotechnology, biotechnology and ICT based on literature studies and interviews with researchers, companies and business entrepreneurs Output: Present and future innovation paths and their environmental potentials and risks
Part 3: August- December 2004	Case studies about present and possible future applications of the technologies and the related business and environmental potentials and risks Output: Socio-technical visions for future applications within specific application areas and the related business and environmental potentials and risks
Part 4: December 2004 – April 2005	Strategic policy recommendations for integrated environmental and innovation policy measures related to technology areas within nanotechnology, biotechnology and ICT Output: Policy recommendations in relation to the technology areas and strategies for integrated environmental and innovation policy
Part 5: January – September 2005	Dialogue and dissemination Workshops and conference Output: Main report. Articles for different target groups

The research within each of the three technology areas has been composed of the following elements:

- Desk research based on literature about the dynamics of technological change and environmental potentials and risks related to the technology area, including the role of governmental regulation
- Interviews with researchers and other stakeholders in relation to research and innovation within the technology area about present and future dynamics, including environmental aspects and their role in research, innovation and applications
- Characterization of the shaping of innovation paths related to the technology area and the environmental potentials and risks and their role in research, innovation and applications

The concrete design of the analysis within each the three technology areas is described in the beginning of each of the technology chapters (chapter 3: ICT; chapter 4: biotechnology; chapter 5: nanotechnology).

1.6 Overall project results

The project has developed the following type of results:

- An overview of the environmental potentials and risks related to the three technology areas
- Methodologies for assessing the shaping of environmental aspects of technology areas in foresight projects
- Considerations about areas where the Danish innovation system could have environmentally related business potentials in connection to the three technology areas.
- Analysis of policy measures enhancing an integrated focus on environmental and innovative aspects in relation to ICT, biotechnology and nanotechnology

- Policy recommendations based on the analysis of policy measures

An important element in the policy measures and the policy recommendations is the interaction and integration of policy measures focusing on environmental aspects, research, innovation and areas of application in relation to the three technology areas; including

- Aspects of governance: platforms and methods for decision-making and the participation of different actor (stakeholder) groups
- Interaction with Danish and EU policy initiatives, like Danish High Technology Foundation and EU's Environmental Technology Action Plan (ETAP) (Commission of the European Communities, 2003)
- Guidance of research and research policy to include environmental aspects
- Integration of environmental aspects in policy support for strategic innovation
- Regulation areas of application in production, trade and consumption

Interviews and three workshops on plastics, on intelligent products and processes, and on policy, respectively, and an international conference on eco-innovation (where a draft of this report was presented[2]) have contributed to dialogue and knowledge building on competences and on policy. Participants in these have included companies, public researchers, governmental authorities, consultancies, and environmental and consumer organizations. These activities have further demonstrated the value, if not necessity, of continuing such dialogue processes, because they can contribute to knowledge building and exchange on technological and environmental dynamics, and on societal and policy drivers for innovation with an environmental perspective.

1.7 Introduction to the structure of the report

Chapter 2 presents the theoretical and methodological framework for the green technology foresight by presenting the analytical approach to the analysis of innovation paths, environmental aspects and policy recommendations for combined environmental and innovation efforts.

In *chapter 3* the present and possible future innovation paths within ICT development and application and the related environmental potentials and risks are analysed. Focus is on the environmental knowledge base, design and control of processes and products, intelligent products and applications, and transport, logistics and mobility.

In *chapter 4* biotechnology applications with the potential of increasing fermentation efficiency, reducing resource use, reducing chemical use and contributing to pollution remediation have been analysed. These applications have been related to general biotechnology development, and the drivers for exploiting the environmental benefits discussed.

Nanotechnology is analysed in *chapter 5*. A general mapping of the public and private innovation activities has been made, pointing to possible application with environmental perspectives, as well as pointing to potential health and safety issues which have to be addressed. The domination of early stage

[2] Eco-innovation: Potentials and challenges of tomorrow's technologies Perspectives for business, Europe and the environment High Level Conference, Copenhagen, 19-20 April 2005 (see http://www.frontlinien.dk/eco/index.htm

development and R&D activities has lead to a focus on the role of environmental perspectives in the search and R&D agenda setting.

Chapter 6 summaries the analysis of the three technology areas and develops recommendations for policy initiatives addressing interaction and integration of policy measures focusing on environmental aspects, research, innovation and areas of application in relation to the three technology areas in Denmark and internationally. Recommendations for the organization of decision-making with a broad involvement of stakeholders (governance) is developed as an integrated part hereof.

2 Green technology foresight of generic technologies

This chapter presents the methodological and theoretical framework for the project. The first part of the chapter introduces the methodological and theoretical approaches, followed by more detailed presentations and discussions in the following paragraphs.

2.1 Introduction to the methodological and theoretical approach in the project

Green visions have been developed by different stakeholders for all three areas of generic technologies that are in focus in this foresight project.. ICT is often presented as an immaterial technology, because it handles information and is supposed to substitute other material processes. Biotechnology is often seen as potentially environmental friendly because it is based on organic materials and biological processes and nanotechnology as technology, which for example might enable reductions in resource consumption or environmental impact due to the tiny dimensions of devices. But most of these assignments of environmental performance as properties to the generic technologies as such are not satisfactory for an empirical and analytical approach to the impact and potentials of new technologies, as indicated as the aim of this project.

The social shaping approach to technological change (Bijker, 1995) (Sørensen &Williams, 2002) and historical studies of technological development (for example Hughes, 1987) have demonstrated the mutual influence of science and society on technological development. A linear understanding of technological change, where research is seen as the most important basis for technological development and thereby also for the environmental impact of technologies, does not in a satisfactory way explain the dynamics of technological change and the interaction between research, development and application of technologies. Technology should be seen as a "bricolage" (Latour, 1999), a mixture of different elements, and technological change as a continuous process, where technologies and their environmental aspects are co-produced by a series of actions taken in research, development, implementation and application.

Through the so-called IPAT-equation, $\Sigma I = P \cdot A \cdot T$, it is possible to illustrate some elements in the dynamics of the overall burden on ecosystems and natural resources and some of the challenges facing future societal and technological change. In the IPAT- equation, first presented by Ehrlich & Ehrlich in 1991 (here from Gladwin, 1993) the following elements are included: I = the total environmental impact of human origin, P = the population factor, i.e. the number of people, A = the economic factor, or more precisely the 'affluence' or resource consumption per capita , T = the technological factor, i.e. the environmental impact per unit of consumption. The simple correlation captured by the equation is that, everything else equal:

- the more people on earth, the higher the environmental impact
- the higher the consumption per person, the higher the environmental impact

- the higher the impact per unit of consumption, the higher the environmental impact

With an increase in the world's population of 50-100% in the future and increased economic welfare by many people in the industrialized countries and the newly industrialized countries, the challenges for future economic, social and technological changes are clear (see for example Spangenberg, 1995). There is a need for more resource efficient consumption patterns, more resource efficient technologies and an increased focus on reduction of environmental impact and resource consumption in strategies for research, innovation and different consumption areas.

The social shaping approach to technological change and the focus on the mutual influence of science and society on technological change implies, in relation to the IPAT-equation, a focus on the dynamic interaction between consumption or affluence (A) and technology (T) as these often are interrelated. The weakness of the equation is that is easily can lead to the assumption that it is possible to isolate and calculate each factor individually and compare different technologies, but this is only the case in very specific situation of simple substitution.

The social shaping approach and the combined focus on consumption and technology imply that environmental aspects and especially the magnitude of their impact cannot always be assigned as properties to materials or processes per se, but are shaped during activities of research, innovation and application in interaction between technology and society. Seemingly rather identical technologies can be applied and handled in very different ways and contexts resulting in different environmental loads. Nobody would, for example probably disagree in future developments and uses of sensors, which enable measurements of concentrations of chemicals in nature and helps in reducing hazardous uses and outlets. However, environmental NGO's and researchers within cleaner technology would probably not agree if the sensors only were used for measurements in nature after the emissions from different facilities have taken place. Neither if the sensors were said to enable less focus on prevention at the source of emissions in the facilities due to the better possibilities for measurements in nature and related ideas of optimal use of natures capabilities. Hybrid cars have less environmental impact than cars with combustion engines, but the important thing is not only the principle of hybrid cars, but also which cars are developed and sold and which amount of transportation is needed and sustainable in society. The use of organic material for production of bioethanol might sound as an environmental friendly process by substituting hydrocarbons, but the actual environmental impact depends on the type of organic material (is it organic waste or plants grown especially for bioethanol) and the alternatives to use of organic material for example for energy production through incineration of the organic matter.

These examples illustrate how environmental aspects of science and technology are shaped not only during research and innovation but through the implementation and contexts of application in the interaction between technology and society. They also demonstrate that the generic technologies often have to be combined with already existing and even new complementary technologies to reach the level of practical application (Wengenroth 1993, Freeman & Perez 1988). The generic technologies do not provide environmental improvements of their own, but in conjunction with their context of application and other complementary technologies (Andersen & Jørgensen 1997).

A technology cannot be characterized as either good or bad in relation to the environment. Wind turbines are widely recognized as an important element in a strategy for reduction of CO_2 emissions to the atmosphere, but there are at the same time environmental problems related to the use of glass fiber for the wind turbine wings due to problems with the waste from scrapped wings. An environmental assessment shall include all the environmental risks and the environmental potentials and weight them against each other. This weighting may sometimes not be done in a quantitative way due to costs and uncertainties, but should still be carried out as an informed dialogue between different stakeholders. A demand for quantification might in some cases imply that a number of environmental aspects would not be included in the environmental assessment, whereby the environmental assessment might loose its credibility compared to the mentioned type of informed dialogue.

Another aspect of the assessment of environmental impacts of a technology will include whether the technology will substitute previous technologies (with other environmental profiles) and whether it adds to the stock of products consumed. For example whether a fuel efficient car will substitute a more fuel consuming car or just will be added to the fleet of cars in the household or the company has an important impact on the environmental performance of the new technology. Reaching the full potential of a new technology may be dependent on the way it substitutes existing technologies and practices. This is a question of the societal dynamics in the field of application: whether e.g. the transportation needs increase due to a longer distance from home to work. Another example: will the possibility for virtual meetings via videoconferencing or web cam dialogue substitute physical meetings and thereby reduce the amount of transportation? Or will the overall internationalization and globalization of research and businesses increase the amount of travelling so much that the impact of videoconferencing and web cam dialogue will be marginal compared to this increase?

The role of technological foresight is to highlight these interdependencies and to identify those processes in the co-production of technology and society that are crucial for the environmental performance of the technologies in question. There is as mentioned no simple answer to the impact of the three generic technologies studied, but a need to detail methodologies that can identify those processes and important decisions that produce the environmental and other characteristics of the technologies in question (Teknologirådet 1999). This leads to the need to understand the role of policy in the development of new technologies. The policies relevant in this analytical context are not limited to research and development policies nor environmental policies, but to a broader field of innovation support, investments and regulatory efforts exercised by government. Innovations and applications of generic technologies are not at all limited to be the results of actions by government, they are the result of the interactions between a larger number of commercial and other stakeholders. Therefore a more relevant perspective on the process of development and application is to view technological development as the result of the societal governance of technological change. In this perspective governance is understood by how power is exercised, how different actor groups are given a voice and included in – and some times also excluded from – the development process, and how decisions are made on issues of public concern. This perspective on policy making has increasingly come into focus in the field of technological change and also sustainable development.

Another important aspect of the foresight process is the identification of visions and their role in the shaping of technologies. Genetic engineering has demonstrated how scientific research is informed by tacit visions and imaginaries of the social role of technology (Grove-White et al 2004, p. 3). Although utopian these visions form the basis on which research priorities are negotiated and planned. However, these visions are seldom subject to public discussion and debate, before the research priorities are made. Such visions need to be more articulated by their scientific authors and subjected to wider social deliberation, review and negotiation (Grove-White et al 2004, p. 3). Controversies around such technologies should be seen as necessary and productive from a societal perspective. The reasons for this are at least two-fold (see e.g. Norges forskningsråd 2005, p. 39-40):

- from a democratic point of view: the citizens have to live with the consequences of this research and the products and since the public funds for research and development are limited the priority given to certain types of research will limit the funds available for alternative strategies for achieving the same types of values, and
- from a pragmatic point of view: citizens and NGOs can contribute with other perspectives than the researchers and other experts due to other experiences and other values.

The focus on governance should not only be on the need for communicating risks from researchers and government to the public. A more comprehensive concept of governance is needed, learning from the earlier experience with for example nuclear power and genetic engineering. Structures and processes should be established so they enable the involvement of citizens, consumers, users, employees etc. and their organizations in the assessment of the legitimacy of the problems and the solutions addressed by the technologies and their proponents. The processes should include dialogue about risks related to the problems and the solutions in focus, but also the social and economic set-up around the research and innovation, including who is in control of the technologies and who is benefiting from the technologies.

This focus in the technology foresight implies that technologies are not seen as independent from societal development, but as products of the society and as a picture of an understanding of societal needs, possible future users etc. The experience from genetically modified food show that big expenses for research and innovation might not become transformed into products on the market, if the products do not have the necessary societal legitimacy. Therefore the utilization of generic technologies in a democratic society are highly dependent on the participation and informed consent of the broader group of stakeholders involved in implementing and using the new technologies.

2.2 Analytical approaches employed in the project

This ‘green’ technology foresight has been based on five different types of approaches in order to collect and analyze information about ongoing research, development processes and applications including also plans and visions for future research, development and applications:
Analysis of present, emerging applications of technologies within the three technology areas. The impact of company and other stakeholder practices, structural conditions in existing and emerging value chains, and patterns in the environmental potentials and risks. This has also included surveys of the prerequisites for further dissemination and implementation.

Analysis of mechanisms of prioritization in research and innovation, the role of existing knowledge regimes in research and innovation, and visions shaping and framing the innovation processes, including the role of environmental concerns in research and innovation.

Surveys of dialogue processes among carriers of the three technological areas and actors from environmentally important Danish product areas and how they envisage possibilities of applying technologies for environmental improvements within the three areas.

Development of scenarios for probable, future innovation paths and possible alternative innovation paths. Following the findings from these scenarios recommendations for integrated environmental and innovation policies. Contrasting the environmental potentials and risks related to the three technology areas with the societal discourse on environmental problems goals and targets and discussions of whether there are better ways solving important environmental problems.

The analytical approaches presented above have been based on theories of:

- Research and development processes seen as socio-technical processes shaped by actors, where persons, artefacts, theories, visions etc. (consciously or taken-for-granted) are assigned roles in research, innovation, and use of technology. Theories about actor-networks, laboratory programmes and techno-economic networks are used.
- Innovation theory focusing on processes of stabilisation and transition in innovation systems, including theories related to path dependency, path creation, and sustainable transition.
- Environmental assessment organised as social and scientific processes by using methods like life cycle assessments, chemical assessments, and methods of dialogue-based environmental assessment, where the focus of the environmental assessment is shaped in the interaction among actors.
- Governance of science and technology as policy network processes involving many different stakeholders and combining different aspects of innovation and regulation of new technologies.

The following paragraphs will describe the different theories that have been applied in the project, explain how the interviews with researchers and companies have been conducted, and how the construction of possible future innovation paths has been done based on information from literature, interviews with researchers and companies etc.

2.3 Social shaping of technology

The social-shaping of technology approach (SST) approach seeks to identify spaces and situations, where sociotechnical change can be analysed, addressed and politicised (Clausen & Yoshinaka 2004). Thus, SST is a broad term, covering a large domain of studies and analysis concerning with the mutual influence of technology and society on technology development. In short, actors and institutions undergo to varying degrees mobilisation, displacement, and reconfiguration (including the establishment of new actors and institutions), as an integral part of the course of technological development.

A key feature of SST is the lack of à priori distinction between the technological (content) and the social (context), respectively. To problematise one facet is to necessarily involve the other (Callon 1986). In this sense SST grapples with technical and social dimensions as an inextricably intertwined unit of analysis. Whether in the development of technology or in its practical, everyday use, the sociotechnical co-construction of technology and social and environmental aspects becomes manifest. This demonstrates the contrast to the traditional view where these are seen as separate fields of study with their own unique properties and consequently are treated separately.

This approach goes against the understanding of technology, which rests upon the attribution of rather *well-delineated, unchanging* properties of technology itself. In SST issues concerning technology are always of negotiated orders, in terms of how issues are raised, as well as in terms of how they come to be resolved. In the case of emerging technologies, it is therefore most fruitful to approach relations between technology and society with a focus on actor choices, strategies and sociotechnical learning and adjustment at the forefront of the research process: What may be posed as a relevant problem regarding the technology, for whom the problem may be relevant, and by whom it may be posed as such, are matters of which form the negotiations unfold in the process of technological development. This approach, though, does not imply that material and social impacts are just a matter of negotiations and power relations, they are seen as manifest and as an integral part of the overall process of development, but also as dependent of how these manifestations are expressed and represented by the involved actors.

Whether in the aspects of design, planning, implementation, or eventual use of technology, SST's analytical stance seeks to draw the understanding of technology into the realm of social influence. The degree of influence on technological change, which may be exercised by individual actors, depends on their particular relation to and engagement with respect to the technologies in focus (Bijker 1995). There are choices in the process of technological development and domestication that may be open to discussion and influence. The key point has been to do away with *deterministic* notions (social and economic determinisms also) about technological development and technological change in society and the following simple assignment of specific, characteristic properties and (environmental) impacts to a technology. The view being, that neither technology, nor social forces alone, sets the course of societal change and choices concerning technology's influence in this regard, but that these are the result of the process of application and use.

Actor-visions, strategies and resources thus play into these dynamics, and particular actors' status may change as a consequence of such interactions. The social dimensions of the technology too are shaped, to support and to sustain particular needs, e.g. through the establishment of new actors and institutions. Instead of taking the driving forces or the concerns for granted, the approach opens up for a wider basis of action as to what may be deemed salient, as well as to what the scope of relevant actors, their positions, and their interaction may entail. In this regard, the SST approach is sensitive to political processes through which actor-positions are identified, negotiated, and redefined, in conjunction with the way technology becomes manifest.

2.3.1 Laboratory programmes

The concept of laboratory programmes is used in the analysis of how researchers organise the focus of their research and is based on the assumption that research processes are not arbitrary, non-biased search processes. Through the concept of laboratory programmes it is possible to identify what is influencing the choices and drawing the attention of the researchers. This concept argues that the "world" is researched the way the researchers understand the world, which could be called the researchers' "map" of the world. This means that research in this foresight project is analysed as researchers' simple search for solutions to well-defined problems. Rather the problems are seen as shaped parallel to the solutions developed during the research, when certain achievements are reached in the research process.

This implies that sometimes solutions are found first, and afterwards the researchers try to find societal problems, which they think could be solved by these solutions. This determines what is taken into account as legitimate elements to be included in the process as problems, parameters etc. within a researchers understanding and what is outside an understanding is shaped at the same time. The discourses around genetically modified (GM) food and plants show examples of such a reverse search process and a reframing of the activities. GM researchers and companies have pointed to pesticide resistant plants as an efficient agricultural strategy while after critique from the environmental movements the use of GMO was translated into an environmental strategy due to its claimed potential for reduced pesticide consumption. However, other researchers and the environmental NGO's pointed to the risk of getting locked in to a pesticide-dependent track for ever and the risk of transfer of genetic material coding for pesticide resistance to other related plants.

A laboratory programme will become more stable when instruments and theories are attached to the program and alignment processes takes place, where physical objects, actors etc. are given roles that mutually supports the research activities and provides them with a legitimate perspective.

2.4 Techno-economic networks

During the identification and analysis of emerging applications and the priority mechanisms in research and development, the techno-economic networks, which the interviewees (researchers, companies etc.) either are part of, or which they (directly or indirectly) anticipate will be developed in the future as part of possible future applications, are identified. As part of the analysis of the techno-economic networks, focus is on the dynamics between the past experience of the interviewee, the ongoing activities and their thoughts about the future development and applications. It is also important to analyse relations to existing innovation paths and how these seem to have an impact on the research and innovation or how the innovation paths and the companies and institutions shaping and "carrying" them might be challenged or might be enrolled in certain visions for the future.

The focus on techno-economic networks supports the analysis in the following two ways:

(1) In the analysis of *the emerging applications* of a technology it is necessary to understand the background for the breakthroughs, the dead ends etc. in the

research and development activities. It is not enough to know whether it now is possible to manufacture for example a certain type of bio-chip, also whether this is based on a certain type of equipment, material, co-operation with others, demand from clients etc. is important knowledge. This will tell about path dependency and path creation in research and development (and thereby also the potential influence of certain equipment, clients etc. in the future). It is also important to understand the technological systems around the applications like necessary supply of energy and materials, standards, competencies etc., which are emerging or need to emerge, so that relevant life cycles and environmental aspects can be identified and prerequisites for further dissemination can be analysed.

(2) In the analysis of *research and development* it is important to understand the background and the prerequisites for the expectations the actors have: What is the role they are anticipating that for example nanoparticles will have (for example a certain behaviour in terms of reactivity, stability etc.), who are expected to be the future users, in which technological systems does this imply that the nanoparticles etc. will be integrated. What are the necessary scientific and technological breakthroughs which are considered as necessary in order to obtain the results and obtain a 'working' version of whatever component it might be? Hereby it is possible to develop a picture of the future research needs as seen by the actors. These pictures might later on become the basis for the development of recommendations for future research, regulation etc. The shape of possible future applications will also enable the sketching of elements in some future life cycles as basis for life cycle based environmental assessments of the environmental potentials and risks.

2.5 Technological trajectory changes

While technological developments in many areas may seem fuzzy and multifaceted, developments in specific areas and applications of technologies often shows more specific and structured paths. Research in new technology has, among other things, supported the observation, that new technologies are far more formable during the process connected with implementation and further development than previously assumed. A sceptical attitude thus exists among researchers and enterprises toward assessments of the future of technology that are based on mechanical predictions. The fact that technology is still undergoing change makes the study of processes of change just as important as the functional understanding of technology. In addition, experts can also bring about particular views about what research and development can contribute in the years to come. Ideas and expectations that research will have an impact on practice – if only the right understanding of the perspectives can be established – is a natural part of the driving power behind a great deal of research.

It is also typical that much professional reservation exists about the significance of the role that visions play in research results. As a result, researchers are reticent about discussing such things, unless it should just happen to be connected with promoting a research area in the competition for funds. It is also a problem, because visions about future development are very much involved in setting the research agenda and supporting the choice of areas to work on. This supports the recognition of certain paths of development that seem to be sustained and gain momentum in the process of development. In the field of innovation and evolutionary economics these paths or patterns have been phrased technological trajectories. In the following some key aspects of this concept will be discussed.

In evolutionary economic theory innovation is seen as inherently evolutionary and cumulative. The core theme is the adaptation of firms to continuously changing market conditions. Emphasis is put on the firm as a production unit and on technological innovation as a major driver of change (Dosi et. al, 1988). Building on biological metaphors, economic activity is seen as fundamentally evolutionary; competition then, is the interaction between partly purposeful, partly random elements creating *variety* and forces *selecting* the behaviours that are to survive (stay in business) (Nelson & Winther, 1982).

Evolutionary change is the sum of decentralised processes of discovery (Dosi, 1991). Evolutionary change is seen as the opposite of revolutionary change that is an emphasis on respectively gradual change emerging from multiple separate interconnected learning and selection processes versus rapid governed change (Nelson & Winter, 1982).

Learning, as all action, is supposed to be routine-based and close in following existing attention and search rules. Learning is based on past experiences preserved in the knowledge base and embodied in routines. Path-dependent learning implies that a firm's knowledge base is theory-laden and upholding inner consistency.

Early proponents of such a paradigmatic approach in economics are Dosi (1982) with his concept of "technological paradigm" as well as Freeman and Perez (1988) with their techno-economic paradigm discussion and the introduction of "natural trajectories" by Nelson and Winter (1982). The basic argument is, inspired by Kuhn (1970), that technology development, parallel to scientific work, follow certain heuristics. Dosi (1982 p. 152) defines a technological paradigm as "a model and a pattern of solution of selected technological problems, based on selected principles derived from natural sciences and based on selected materials technologies", (p.152). A technological trajectory is the pattern of conventional problem solving activity within a given technological paradigm; i.e. it is the normal problem solving activity determined by a paradigm.

The technological trajectory emerges because the technological paradigm has a strong exclusion effect. It embodies strong prescriptions on the directions of technological change to pursue (positive heuristics) and those to neglect (negative heuristics) (Dosi, 1982). The efforts and imaginations of researchers and practitioners are focused in precise directions while they are "blind" with respect to other technological possibilities. Also technological paradigms define an idea of technological "progress" related to the economic and technological trade-offs of a given technology (ibid.). The trajectory then, is the movement of multi-dimensional trade-offs among the technological variables, which the paradigm defines as relevant, resulting in a certain technological path. A trajectory is more powerful the bigger the set of technologies it excludes (Dosi, 1982).

Focus is on the evolution of trajectories through selection mechanisms. Dosi (1982) argues that there are generally weak ex ante selection criteria over trajectories; for an innovator it is highly difficult to assess which trajectory is going to win. The economic forces, together with social and institutional factors, will operate as selective devices as new trajectories emerge at the expensive of the old. Gradually the determinateness of selection increases as more and more trajectories are ruled out. This argument lies in line with the discussion on product innovation cycles (Abernathy and Utterback, 1978). There are generally high shifting costs in changing trajectory, depending on the relative power of the old and the alternative trajectory. The institutional set-up supports the existing trajectory because of economies of scope and learning.

Technological communities are important for shaping the search processes (Dosi and Malerba, 1996). These are seen as the group of practitioners, usually engineers, researchers and scientists working with similar technologies, e.g. within the same sector and the supporting scientific institutions. Community members are considered to share similar heuristics through joint experiences of practice but also through a shared education system (Nelson and Winter, 1982).

The trajectory discussion places firm learning within a wider systemic and institutional change It is a recognition of underlying a priori knowledge structures which extends far beyond the single firm. Non-market institutions, notably the education system and the wider societal norms play significant roles in forming the dominating technological trajectories. The emerging innovation system perspective builds on these cognitive considerations (Freeman, 1987; Freeman, 1995; Lundvall, 1992 (ed.); Nelson, 1993; Edquist, (ed.) 1997). The wider institutional context is seen as shaping firms' innovation process in decisive ways. The institutions (sets of routines, norms and laws) work first of all as reducers of uncertainty and therefore also of the amount of information needed. The implications at the firm level are that the institutional set-up partly determines a firm's *search space*.

There is a tendency to provide a strong technology push explanation of trajectory change within industrial dynamics. The interest remains predominantly with which firm/sector is winning the technological race, which takes place at the expense of investigating the processes of innovation more carefully.

2.5.1 Trajectory change and the product cycle

The conditions, noticeably uncertainty, of trajectory change differ in the various stages of the product cycle. Other authors have emphasised how the interfirm interaction is eased by the development of standardised interfaces. E.g. Langlois (1992) refers to standardised connections between stages and fixed task boundaries.

In the *pre-paradigmatic stage*, the design is fluid involving multiple costly prototyping, until there is evidence that an industry standard, the dominant design, emerges. In this stage there are weak appropriability conditions and imitation is strong. Competition is basically on design, that is, on deciding the standard. Manufacturing processes are loosely and adaptively organised and it is important that the innovator is intimately coupled to the market so that user needs can fully impact designs (Teece, 1986, Lundvall, 1985). It is in this highly uncertain phase, when it is uncertain whether the innovation will become a dominant design or not and the risk of exaggeration is obvious, that it is difficult to persuade the firms with complementary activities to make investments specialised to the innovation. In this fluid phase the uncertainty as to future innovation paths may be great (ibid.).

When systemic innovations are so radical that they involve the pioneering of industry standards the coordination difficulties are great and there may be a battle of industry standards (Teece, 1986; Chesbrough and Teece, 1996).

There may be complex protocols and differing interests among the parties related to competing designs, each trying to become the dominating (selected) standard. In this phase interorganisational coordination and information flows will be intense (Teece, 1986). Market leadership is required to advance standards and it is often big players who break the logjam among rival technologies. Chesbrough and Teece (1996) mention the example of IBM's PC innovation where the reputation effect of the trade name alone was enough to pull the complementary assets together without contracts.
If we turn to the *paradigmatic stage*, as industry standards increasingly become accepted, the competition on design weakens and so does the imitation efforts accordingly. Economies of scale and learning in the form of process innovations are important. Competition is on price but also this becomes increasingly less important as prices harmonise. Rather than the core technology which is easy to imitate, the access to and control with the complementary assets becomes the critical competitive factor (Teece, 1986). Teece (1986) argues that it is likely that the imitators, with less developing costs and less restricted by asset specificities, rather than the innovators will come to possess the dominant design. The lower the relative costs of prototyping the greater the possibility for the innovator of shaping the dominant design. The great risks of the innovator as well as the holders of complementary assets are thus accentuated, and thereby implicitly, the costs of persuasion/the high dynamic governance costs.

Reddy et al (1989) emphasizes the codification process in a wider standardisation process in the product life cycle. In the very early stages of a technology, the standardisation activities are focused on the creation of a common language. Next, the performance expectations and procedures for inspection, testing and certification are addressed. At the stage of emergence of a dominant design the activities are oriented towards dimensional and variety reductions. The standardisation process never finishes, but continuous with revisions and evaluations through a product's life cycle (Reddy et al., 1989).

It is central to clarify that the battle between competing trajectories is not only one of technical standards but may also be described as a battle of conflicting heuristics. Innovators may have to develop different capabilities, theories and understandings to pursue a new innovation path. A classic example of such conflicting trajectories is the electric car versus the traditional car, where the former builds on some very different design and construction principles and a divergent supporting technical infrastructure, much to the disadvantage of the electric car (Truffer and Dürrenberger, 1993). The uncertainty is thus not only one of investments but of cognition. Creating confidence in a standard based on a trajectory that is hardly understood is naturally associated with great difficulty. Such radical changes are slow and have to await a codification process and gradual acceptance of principles through multiple interactive learning processes between supporters and opponents, and possibly succeeded by changes in education systems and other supporting infrastructure.

2.5.2 Different notions of trajectories

There is some indistinctness concerning the concept of trajectory, as it is used in different ways and at different analytical levels; it is unclear, and has not been discussed within the research on technical change, where trajectories are embodied and how they are delimited.

Within the evolutionary economic tradition, technological trajectories are usually seen as aggregate market phenomena, usually only realised ex post. Most refer to trajectories of specific technologies and therefore related to sector development, while others discuss trajectories as regional phenomena (e.g. Quévit (ed.), 199; Kodama, 1996). This indistinctiveness of the trajectory concept is also found in the works of the main proponent Dosi (Dosi, 1982; Dosi and Malerba, 1996), and may be derived from the fact that he defines trajectories quite flexible, existing at different levels of generality, and involving potentially a cognitive and/or a more technical cumulativeness (Dosi, 1982).

Also the early analysis of Dosi differ somewhat from the later interpretations of trajectory change; thus Dosi and Malerba (1996) recently spoke of trajectory change as a co-evolutionary process guided by the surrounding institutions:

Micro-level entities path-dependently learn (and get stuck), but sector-specific knowledge bases and country specific institutions restrict the 'seeding' of the evolutionary process and also channel the possible evolutionary trajectories. Given the initial conditions and the institutional context, these innovations spread and set in motion a specific trajectory of competence-building and organizational evolution (Dosi and Malerba, 1996 p.15).

The early (Dosi, 1982) emphasis on trajectory change as discontinuous and the focus on technology development at the market level (as typically perceived by analysing patent data ex post) is replaced by an emphasis on trajectory change as emerging and with a starting point in the firm, consistent with the later Dosi's stronger emphasis on firm strategizing and firm learning as opposed to a focus on the market level.

2.5.3 Exploitation-exploration- attention and search rules

Inspired predominantly by the behavioural school industrial dynamic theory emphasises the exploitation - exploration dilemma. The trajectory change discussion feeds into this theme. Innovative activities which are the "normal progress or innovative effort" are in accordance with the existing trajectory and are seen in opposition to an "extraordinary innovative effort" which are departing with the existing trajectory (Dosi, 1982). The former is usually associated with incremental innovations and thus continuity in the technological innovation, the latter with radical innovations and discontinuity in the technological innovation. Exploitation then is firm learning within a specific technological paradigm, and exploration as learning challenging given paradigms to some degree.

Exploitation and exploration calls for different organisational set ups (Lundvall, 1985). On the one hand, the role of information channels and codes for information exchange means that some degree of organisational *rigidity* is a fruitful element in the learning process. Learning within the existing information channels and codes allows for effective exploitation. On the other hand, there is a need for *flexibility* in the learning relations in order to open up for the organisational and normative breaches of the radical innovations. Radical innovations, or exploration, often involve exchanges of the participants given the embedded nature of much knowledge and the need for new inputs from a variety of sources. Radical learning is thus associated with a broad platform of interaction, i.e. a great number of participants and therefore flexible information channels. However, upholding information channels with many participants is costly. And establishing new channels and codes is associated with high set-off costs. According to this argument, there is a fundamental contradiction between efficiency and radicality in learning, as they are bound up with respectively stable and flexible learning relations. This accentuates the difficulties of radical innovations.

Recognition of the firm heuristics makes it easy to understand the tendency to carry out exploitation in the firm rather than exploration. Obviously, greater investments are needed for creating new cognitive resources and new attention rules than exploiting those already available in the firm (Boisot, 1995). However, the possibility of exploration or radical innovations, other than those made by new actors, is in need of explanation. Generally, we still have little insight into how a firm's knowledge base and heuristics are developed and transformed over time. As a consequence the shaping of firms search and attention rules influencing the early phases of the innovation process, the crucial phase of problem identification and problem definition, are given little attention. As a result of this industrial dynamics only addresses incremental change within existing paths while radical change and path creation remains unexplained.

Penrose (1959) is an exception here. Her strong emphasis on firm resources allows her to relate the shaping of a firm's knowledge base to the development of firms' search rules and entrepreneurial expectations. It is the experience and knowledge of a firm's personnel, which determine the response of the firm to changes in the external world and also determine what it "sees", notably the perception of "demand conditions". Integrating the resource based perspective seems essential for an understanding of trajectory change processes (Andersen, 1999).

2.5.4 Applying the technology trajectory approach in technology foresight

Important questions in technology foresight in the analysis of path dependency, path creation and attention and search rules in research and innovation are:

- How fluid/settled are the trajectories (stages in the product cycle, strength of path dependence)
- What defines the trajectories? Are they more cognitive or more technical? What are the expectations (attention rules), the important theories and skills (search rules) and investments?
- How many are there and how are they competing? Are there e.g. a few dominating ones or many at the same level?
- Can the main carriers (proponents) as well as opponents of the various trajectories be identified?
- Can the distribution of the trajectories be delimited with respect to a)professional, b) cultural and c) geographic proximity (in Denmark as well as internationally). Are there distinctive technological communities defined by different trajectories?

- In which way do they shape the search processes?
- What forces strengthen and preserve the emerging trajectories and what forces hinder them?
- All in all, what do the identified technological trajectories tell us about the pace and direction of technological change of the three generic technologies?

2.6 Identifying visions and constructing paths of development

Some of the actors involved in research and technology development are what can be called enactors of one (or more) of the technology areas. This means they build, among themselves, a repertoire of promises and expectations and strategies how to position the research or the technology in focus. They might feel forced to promise a lot in order to secure future funding, because if they don't do that they might not be able to mobilise (more) resources for research and innovation activities. Other actors might more be outsiders or comparative selectors, whom don't necessarily buy into these promises, but are more watching whether a certain field seems to be relevant for their own interests, compared to other possibilities. It might also be possible to experience 'mutual positioning', where some actors try to exclude others by for example referring to them as too much into 'hype' in relation to for example nanotechnology (Rip, 2004).

This represents a challenge to the foresight project and to the employed methodology as the identification of existing visions and paths of development is not easily distinguished from the involved actors interests in pursuing their own visions and emphasising certain aspects in their activities e.g. in relation to the environmental concerns. The interviews carried out in the project and the focus created is itself a social process between the interviewee and the interviewing person (Kvale, 1996) and in relation to the object of study. Since environmental aspects are addressed in the interviews, there is the risk that

- the interviewees focus more on environmental aspects than in the normal research practice in order to gain social and political support;
- the interviewees under-estimate the future role of the technology in order not to create too much external interest in its societal impact;
- the interviewees want to avoid problems and is therefore open and transparent.

A way of avoiding the two first situations might be to combine, where possible, data from several interviews or combine information from interviews with written information in order to qualify the assessment of how environmental aspects are seen and whether these are integrated into the research and innovation processes, although written materials of course also are socially constructed and might be aiming at fitting into a certain agenda-building.

But also at the level of development the possible outcome and time frames for research and development will be based very much on the ideas and assumptions of the involved experts. They are so to say themselves involved in constructing the futures that legitimate and accommodate the research results and the ideas for technological developments still to come.
The interviews of different actors have been compared in order to identify mechanisms in research and innovation processes and draw up possible

(maybe conflicting, maybe converging) scenarios. The identification of such possible futures within a scientific or technology area can be based on identification of emerging irreversibilities (Rip 2004) as explained in the following. The thoughts of researchers (and other actors) about the possible futures are based on combined thoughts about technological and social aspects of the future in the sense of thoughts about the scientific and technological progress and about the society, which is going to use or implement this progress. The dynamics of these expectations and the agenda building they are part of can be recognised through (Rip 2004):

- Shared research agendas among actors;
- Collective learning processes, maybe as forced or antagonistic learning;
- Emerging mutual dependencies in network linkages.

Changes might be seen at three different levels, where relations between changes at the three levels are indications of emerging irreversibilities (Rip 2004):

- Macro level: overall societal visions ('rhetorics');
- Meso level: research programmes and investments;
- Micro level: heuristics in actual research practice.

The scenarios enable anticipation of the possible impacts of the scenarios and discussions of whether these impacts are desirable.

An example of a scenario and its possible impact is the development of nanosensors, which are said to become so small and so cheap that they can enable much more measurements of chemicals in the environment, in wastewater etc. Besides the environmental impact from the sensors themselves and the potentials for better environmental management from better data, there could be an indirect environmental impact of the nanosensors, if the development of these sensors makes authorities, industry and the general public belief that "we anytime and anywhere can detect environmental impact". Such an understanding could imply an understanding saying that "we don't need to prevent environmental problems, and we don't need to be cautious" and thereby be a threat to more preventive environmental strategies. In the discussion of such a scenario it is important to discuss whether lack of environmental data hitherto actually has been limiting the environmental management has rather been a question about the level of environmental regulation industry has been willing to accept. If the latter is the case the development of nanosensors might not imply more concern for the environment.

The interviews of different actors should be compared in order to identify mechanisms in research and innovation processes and draw up possible (maybe conflicting, maybe converging) scenarios.
Rip describes important steps in the discussions of such possible futures as (Rip, 2004):

- Socio-technical mapping, including the expectations of the actors.
- Foresight researchers' elaboration of socio-technical scenarios, based on the expectations and containing elements of co-evolution of technology and society.

This leads to an identification of points where paths of development embranches and where decisions about the route to take will have big impact on the further development of technology and society. "Cross roads" has been used as a similar concept in some Danish foresight projects. An example of such an embranchment is the future impact of a focus on (national) security in the US society on the development of nanoscience and nanotechnology R&D activities in US.

2.7 Assessment of the environmental aspects within the three technology areas as social and scientific process

As part of the foresight project a methodology for the assessment of environmental aspects within technology areas has been developed. This development has been an iterative process, where the methodology has been developed along the experience obtained during the project. The assessment of the future environmental aspects is based on the following elements:

- *Life cycle thinking*, which means assessments "from cradle to grave". Some assessments are focusing on present emerging applications and others are based on the information from researchers etc. about possible future applications, which enable the sketching of product chains for assessment of environmental aspects. There is, as earlier mentioned, big difference in the amount of knowledge about the environmental aspects of the technology areas with ICT and biotechnology as the two areas with knowledge about past and present applications and their environmental aspects, In the interviews it has been tried to make researchers and companies describe possible future life cycles, including the raw materials which might be applied.

- *Systems approach*, which implies that not only single techniques or chemicals are taken into consideration, but also the other system elements (products and the related infrastructures etc.), which the techniques, chemicals etc. are part of or dependent of, are, if possible, included in the assessment.

- A *broad, dialogue-based understanding of "environment"*, which not only comprises of quantifiable environmental aspects like wastes and emissions, but for example also area as a resource. The understanding of relevant environmental aspects has been shaped through studies of literature, dialogue at project workshops etc. Focus is not only on quantifiable and standardised environmental aspects, but also on more qualitative aspects like the impact on the understanding of environment and nature. Part of the approach has been inspired by the approach of "participatory life cycle assessment" as described by Bras-Klapwijk, (1998), where the focus of the life cycle assessment is discussed among the concerned and involved actors in order to increase the legitimacy of the assessment among the actors afterwards.

- *Precautio*n as principle, where uncertainty and lacking knowledge is giving favour to the environmental concern. The approach to precaution has among others been inspired by the approach in the European Environmental Agency's analysis of a number of case studies of so-called "late lessons from early warnings" (Harremoes et al, 2002). This inspiration has implied that the assessments as far as possible have included early warnings, accounted for real world conditions and used different types of knowledge, including knowledge from environmental researchers, NGO's, governmental authorities and businesses.

- *Prevention* as preferred environmental strategy, which means focus on prevention of potential environmental impacts during the research and innovation stages and focus on the source and the cause of the se environmental impacts, as opposite to an end-of-pipe strategy only focusing on treatment of wastes and emissions.

Some of the methodological elements in the approach to environmental assessment are described further in the following paragraphs.

2.7.1 Elements of stakeholder involvement and dialogue in environmental assessment

The methodology contains scientific and dialogue-based elements, because it is not clear in advance, which environmental aspects different stakeholders might find relevant in relation to a possible future. Some actors might, for example in relation to enzymes focus on the ability of some enzymes to reduce the consumption of energy and chemicals in an industrial process and will not see the use of genetically modified (GM) microorganisms as a problem, while other actors might see the use of GM-microorganisms as a problem and opt for strategies without such technology. The assessment of the environmental potentials and risks related to the three technology areas is based on a combination of five perspectives:

- The perspectives from other projects and reports identified through the desk research.
- The perspectives of the enactors and proponents of a certain scientific field, product etc., including the environmental aspects they might see.
- The perspectives potential future users of certain processes, products etc. might see.
- The environmental aspects the project group has identified based on the perspectives of the enactors, proponents and potential users and their descriptions of possible future techno-economic networks and the environmental aspects they see.
- The environmental aspects, which other stakeholders, like governmental authorities, NGOs etc. might identify based on the perspectives in A.-D.

2.7.2 Identification of fields of application and core properties of technologies

An assessment of the environmental aspects of the future development within the technology areas is complicated due to the many unknown elements within the future development in research and innovation and the different societal areas of application and consumption. This challenge in the environmental assessment has been dealt with in the following way: By focusing on the societal problems and discourses, which have been addressed in the past and recent development, and on the understanding of societal problems and discourses and application areas, which researchers and companies have addressed, when interviewed about the focus of research and development, it has been possible to sketch possible future areas of application.

The focus on possible fields of application has been combined with attempts to assess core properties of the technologies. Methodologies for environmental assessment of chemicals normally include three basic elements, which could be seen as some important general elements in environmental assessments of generic technologies:

- The properties;
- The amount;
- The exposure of "the environment" to the materials etc.

A crucial question is whether one can talk about generic environmental properties of a technology (comparable to the properties of chemicals or materials), which would allow for very early assessments of the risks related to a technology and thereby maybe contribute to pro-active assessments of all possible applications of the technology. The discussion of GM-crops is an example of assessment of core properties of a technology. Some NGOs say that GM-crops are inherently unsafe, because it is not possible to assess all aspects of the technology in the laboratory and not possible after release to the market to withdraw the technology from "the environment", if unwanted effects are emerging, because the genetic material might have spread to other plants.

IÖW has in a report for the European Parliament used a similar approach, which they call "characterisation of technologies" as a way of getting some first indications about potential problems of one of the nanotechnologies (nanoparticles) before "adverse effects on targets are identified" (Haum et al., 2004). They point to smallness and mobility of the particles, changing chemical reactivity and selectivity, and changing and intensified catalytic effects as properties or aspects, which point to other types of environmental impact deviating from other matter.

It is, however, important to state clearly how such characterisations are applied in an assessment. At a discussion in the nanotechnology working group under the Royal Society and Royal Academy of Engineering in UK December 2003 it was noted in a discussion about effects of nanoparticles that "there are a lot of naturally occurring (e.g. clays) and synthetically produced nanoparticles (e.g. diesel exhaust) which are already present in the environment" (Royal Society and Royal Academy of Engineering, 2003). The aim of the comparison was not clear, but since the negative impact of diesel exhaust and welding fumes on respiration etc. is well-known the comparison cannot be used as an argument in favour of nanoparticles (by saying for example "we have known nanoparticles for many years"). On the contrary, such past health impacts show the need for serious precaution in the future. The use of general characteristics and comparisons is an important aspect for discussion within this kind of assessments of technologies and their impact. Such assessments might be used for regulating a certain technology, but never for acquitting a technology for unwanted impacts.

In a report for the OECD Berkhout and Hertin, (2001) developed a methodology for the assessment of environmental aspects of ICT, which have inspired the environmental assessments within the three technology areas. The approach distinguishes between positive and negative effects of changes within a technology area and between three different levels, where the assessments can be performed, called first, second and third order effects. First order effects are effects connected directly to production, use and disposal of the material or the product itself, like ICT hardware. Second order effects are impacts from the interaction with other parts of the economy through the impact from the fields of application, like for example more intelligent design and management of processes, products, services, product chains etc. The number of products, including the effect on the stocks of products due to limited substitution, is also important at first and second level. E.g. if not all “old” products are substituted with more energy efficient ones, but in stead the stock of products is *increased* with new, efficient products, whereby the total energy consumption might increase. Slow uptake of more efficient process management, whereby potentials are not obtained, is also an example.

Another example of a complicated interaction is the dependence of the growth in the virtual economy, like e-commerce, on the development of faster, more flexible transport infrastructures with greater capacity, whereby the energy consumption for transportation might be increasing. Finally, Berkhout and Hertin focus on third order effects, like changes in growth rates among sectors. Futhermore they see rebound effects as third order effects, when efficiency gains stimulate new demand, which balances or overcompensates the savings or when technological changes in one area interact with chnges in other areas and these changes reinforce or co-shape each other so that the consumption is increasing or expanded (like the interaction between the increasing possibilities for distance work via portable computers ands electronic networks and the increasing globalisation of businesses and the increasing air travelling . It is difficult to assess the role of such rebound effects, but by highlighting potential negative (or positive) rebound effects, themes for future governmental regulation can be identified. Table 2.1 illustrates the methodology for the assessment of environmental aspects of ICT by Berkhout and Hertin as it has been elaborated for the green technology foresight.

Table 2.1
Methodological framework for the assessment of environmental aspects of ICT (adopted from Berkhout & Hertin 2001).

	Possible positive effects	Possible negative effects
First order effects Effects related directly to the technology and its infrastructure	Some substitution of hazardous materials from future electronic products	Environmental impact and resource consumption from manufacturing, use and disposal of ICT hardware New ICT implies a larger stock of electronic products, so that the total consumption of energy etc. is increasing
Second order effects Effects from fields of direct application	Dematerialisation (relative decoupling of economic growth and resource consumption). E.g.: - better process regulation reducing resource consumption and wastes - more intelligent products enabling reduced resource consumption during use	Customised E-commerce might imply increased transportation of small batches of products in a number of parallel distribution systems
Third order effects Effects from changes among sectors or areas of consumption	Growth in less resource intense sectors Changes in life style, e.g. bigger demand for greener products due to easier access to information about the environmental performance of products	Rebound effects, e.g. expanded or increased consumption, like increased transportation due to easier and increased electronic contact among different parts of the world, combined with lower prices on air flights

At the first and second order levels it might be easy to assess the potentials of a certain technology, if an 1:1 substitution with another technology can be foreseen and the changes in first order effects (the induced effects from the technologies, which are compared) easily can be compared and with the changes in second order effects from changes in avoided consumption and emissions through a life cycle assessment. An example is assessments in chapter 4 based on life-cycle assessments of the applications of enzymes for the optimisation of industrial processes by comparing the practice, where enzymes are used, with the past practice. At the third order level, however, the effects of such a change might become more unclear, because the change might not just be a substitution of some energy and some chemicals with some enzymes, if the use of enzymes implies that products manufactured in the optimised process become cheaper and the consumption of them therefore increases. This would imply that a comparison of the impact from the life cycle of the enzymes with the saved resources in a life cycle perspective for the avoided use of some energy and chemicals will not give the full picture of the possible effects at the third level. It is of course difficult to say how a certain technology might become integrated into a certain branch or consumption area, but a comparison with societal dynamics, for example identified in interviews with research and businesses can point to some challenges for the future regulation of a certain technology and its application.

2.8 Governance and regulation

The policy recommendations of this foresight project for integrated environmental and innovation policies have been developed based on the previous described understanding of technological change, assessment of environmental aspects and need for at the same time diverse and integrated policies reflecting the shift towards a governance perspective of the stakeholder interactions and the need for dynamic policy measures and objectives to cope with innovation.

2.8.1 Typology of government regulation

Table 2.2 shows an overview of three genetic types of regulatory instruments that from the outset have been considered in the project. The development of policy recommendations has in itself included a policy network approach, since three workshops during the project have contributed to the development of the recommendations in close cooperation with most of the stakeholders involved in developing, using and regulating the technologies studied.

Table 2.2: Overview of different approaches to governmental regulation (after Schot et al 2001).

	Classic steering paradigm (top-down, command-and-control)	Market model (bottom up)	Policy networks (processes and networks)
Level of analysis	Relationship between principal and agent	Relationship between principal and local actors	Network of actors
Perspective	Centralised, hierarchical organization	Local actors	Interactions between actors
Characterisation of relationships	Hierarchical	Autonomous	Mutually dependent
Characterisation of interaction processes	Neutral implementation of formulated goals	Self organization on the basis of autonomous decisions	Interaction processes in which information and resources are exchanged
Foundational scientific disciplines	Classic political science	Neo-classical economy ('rational economic man')	Sociology, innovation studies, neo-institutional political science ('bounded rationality', uncertainty, learning, interacting)
Governance instruments	Formal rules, regulations and laws	Financial incentives (subsidies, taxes)	Learning processes, network management e.g. experiments, demonstration projects, vision building at scenario workshops and foresight, network building through seminars and strategic conferences, public debates

This schematic presentation of policies is based on a classification and differentiation of policies due to their basic elements and measures. As shown in several studies (se e.g. Boehm & Bruijn 2005) the efficiency and impact of policies is not dependent on the working of single measure independently but on a combination of measures, objectives and their implementation. In the analysis of the environmental impact of the generic technologies these findings may turn out to be an important lesson when identifying relevant policies to support the environmental achievements from the implementation and use of the generic technologies.

2.8.2 Different aspects of governance

Environmental governance can be influenced by policies that build platforms and methods for different actor groups giving them a voice and developing frameworks for how decisions are made on issues of public concern. Governance is thereby also linked to the creation of legitimacy of priorities of problems and solutions in focus in technological change, the level of risk and uncertainty to be accepted etc. An important aspect of governance concerns how boundaries are drawn and issues are being defined as inside or outside and what is legitimate to discuss as risks and potentials. This includes on whose premises these boundaries are drawn and what sort of framing between the social and the technical that is set up. An important aspect is the inclusion and exclusion of actors, and how the drawing of such boundaries is dealt with (Clausen and Yoshinaka 2004, pp. 224-226). Dingwerth describes dimensions of democratic legitimacy in his analysis of democratic governance (Dingwerth 2004, p.23). The three sources or dimensions are a) participation or inclusiveness, b) democratic control and c) discursive quality. Legitimacy through participation focuses on two aspects: the scope and the quality of participation. The scope refers to who participates. The quality of participation refers to how those who are included in the decision-making process actually participate. Various degrees can be imagined from passive like receiving information to more active like participating in public debate, voting, selecting a representative or representing a constituency. Equality of opportunities to participate is seen as linked to the quality.

The idea of democratic control could be seen as passive forms of participation, where control refers to concepts like accountability, transparency and responsiveness (Dingwerth 2004, p. 25). An important aspect is who is actually able to exert control over decision-makers. The degree of transparency concerns the extent to which the affected are able to learn about the decision-making, including its existence and subject matter. Such elements are highly relevant in relation to priorities and agenda-setting in research and innovation. A principle within this aspect of governance is the right-to-know principle, which is supported by the Aarhus Convention. The European Environmental Bureau, EEB, finds that there is need for further implementation in the EU of the Aarhus Convention (European Environmental Bureau 2005).

Finally, the discursive quality is linked to an understanding of discourses as the social space where collective interpretations are constructed and discourses are seen as a long-term consensus-forming process rather than (just) a decision procedure (Dingwerth 2004, p. 27). Elam and Bertilsson (2002) argue in their development of the scientific base for analysis of science, technology and governance that the modern democracy includes the acceptance and legitimation of conflict and accepts that consensus is of a conflictual and contestable nature.

2.9 Summary of foresight approach

As a summary, the ambition with the Green Technology Foresight project can be characterised as:

- Show that environmental impact cannot always be connected to materials or processes per se, but are shaped during activities of research, innovation and application of technologies. Therefore research, innovation and application areas like products, branches etc. are all important policy fields in the regulation of technological change and environmental impact.
- Show that the scope of the environmental assessments of research, technology etc. needs to be defined in an open, democratic process.
- Show that different technological paths might call upon different technologies, competencies, infrastructures etc., so that identification of forks and cross roads for important choices in the future development is important.
- Show that technologies are not single chemicals and materials, but whole systems and that these systems and their interaction with other systems need to be included in the identification and assessment of environmental aspects.

- Show that different solutions to environmental problems might be compared and that the comparison might go beyond the simple comparison of chemicals and resources, and include for example the cultural impact, like the impact on our understanding of nature.
- Identify the ”hype” in relation to potentials for remediation and prevention of environmental problems and identifying what might be or become more real potentials.
- Identify the prerequisites for innovation paths that support the implementation of environmental potentials.

It is a challenge to establish an open, democratic societal discussion about technologies and the impact and about alternative strategies, because researchers and universities today often are depending on external funding, which might encourage them to promise big positive impact of the technologies. At the same time universities more and more engage in setting up companies and taking patents themselves, which might make them less interested in public discussions of the technologies, the impact, the prerequisites for realisation of potentials etc. Maybe the above mentioned ambitions with the Green Technology Foresight project are optimistic, but the project will be an opportunity to get early and open discussions of societal interests making sure that alternative strategies for achieving the environmental promises from the ‘high tech’ areas also become part of the societal debate.

3 Environmental aspects of the development and use of ICT

Thomas Thoning Pedersen, Michael Søgaard Jørgensen, Morten Falch, Ulrik Jørgensen & Ole Willum.

3.1 Introduction

This chapter presents the research on Information and Communications Technologies (ICT). The aims of the research have been:

- To identify areas of ICT application that have been claimed to have or get environmental potentials and understand the shaping of these ICT applications as an interaction between the general dynamics of ICT, the dynamics of the application areas and the dynamics of the ICT applications within these areas
- To assess the environmental potentials and risks and the role of environmental concerns in research, innovation and governmental regulation related to these areas of ICT application

The term ICT is used to describe the tools and the processes to access, retrieve, store, organise, manipulate, produce, present and exchange data and information by electronic and other automated means (UNESCO 2005). ICT is an umbrella term that includes any communication device or application, encompassing: radio, television, cellular phones, computer and network hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as videoconferencing and distance learning. ICT are often spoken of in a particular context, such as ICT in education, health care, or libraries.

The separation of data and information could be a bit controversial in the area of ICT, but the reason for doing so is that the understanding of data and information in the theory of knowledge provides a useful distinction between data and information. Data are the base for information and the distinction lie in the idea that information contains a perception or even an action of the collected data (Nonaka & Takeuchi 1995 p.15). Information is the media that makes the base for action of a person and is therefore filtered by the person's perceptions of the data. Data are basically the objective properties of the environment (Boisot 1998 p.12). This definition may even open for a too narrow understanding of both data and information, as data only can be given a specific meaning in a context where both the production and the retrieval of data is underlying the same frame of interpretation, and where the use of these data as information will include the social and institutional context in which the interpretation takes place, even influenced by the specific situations in which the information is handled. Both the general context and the specific situations in which information is used involve interpretation and association of the information into a broader frame of action.

3.1.1 Methodology

The base for this chapter is three related activities: Desk research, interviews and workshops.

The desk research has been focusing on former research and knowledge about the relationship between ICT and the environment in a wider perspective. The relation between ICT and the society has also been a significant part of the desk research.

The interviews have been carried out with actors from both the Danish research environment and businesses using or developing ICT as tool in their work. The actors have to a high degree been selected by having some relation to use of chemicals, materials or energy resources and not necessarily because of their interest and work with environmental issues. 17 interviews and personal conversations have been carried out (see reference list). Interviews as a social process addressing environmental aspects have the risk of focusing more on environmental aspects than in the normal practice. The interviewees might over or under-estimate the future role of the technology in order to influence the external interest in its societal impact.

A way of avoiding this has been to combine, where possible, data from several interviews or combine information from interviews with written information and discussions at the project workshops in order to qualify the assessment of the environmental aspects. The interviews of different actors, written material and workshop discussions have been combined in order to identify mechanisms in research and innovation processes and draw up possible (maybe conflicting, maybe converging) future development paths. Especially a project workshop January 2005 about so-called intelligent products and processes has been important.

3.2 Overall consideration of Information and Communications Technology

Information and Communications Technology (ICT) comprises of a relatively well developed and in certain areas even mature set of technologies that are integrated in both professional and private settings (Henten 2001 p.11). It would be a too comprehensive work to try describing all possible technologies and their applications. Consequently there is a need for making some generalisations about ICT and also to focus only on some of the applications of ICT. A description of the environmental potentials and risks also opens for a rather broad field of problems and therefore opens for similar problems for an attempt to cover all aspects. It is almost impossible in one report to assess it all. Therefore this chapter starts out by setting ICT in relation to a social and regulatory framework in order to understand the dynamics in the development and use of ICT with emphasis of the situation in Denmark. In practical terms this limits the focus on some of the production facilities for IT-equipment merely not present in Denmark while emphasising the application side of ICT's.

Following this introduction some general trends in the future ICT development is described through a number of future technological trajectories at the functionality level identified in the EU ICT foresight project FISTERA (Saracco, Bianchi, Mura, & Spinelli, 2004). Some application fields for ICT, which have been highlighted as environmentally important in the literature, are presented and a description of possible disruptions in the future innovation of ICT is presented. The future development of ICT is seen as shaped by the interaction between some general ICT dynamics, the dynamics of the application fields and the social and regulatory framework.

The selection of application areas for ICT and the aggregation and generalisation of these will be described more in detail in a later section. The criteria for selection have been the potential positive and negative impact from the application of ICT's in the different areas. Even large, but rather neutral or low impact areas of application have been given less attention.

3.2.1 Political and marketing frame-work conditions

To understand the possible future development and use of ICT in Denmark, it is important to look at the Danish conditions and at more general and global trends. The so-called Digital Denmark from 1999 is an example on how a Danish government wishes to be in front with regard to education and the public access to ICT. The visions show that ICT as area is integrated into the broader context of the political arena in Denmark (Henten 2001 p. 4). An international trend is to shift from a governmental intervention and protectionist approach to a more open political approach with EU and USA as the main driving forces (Henten 2001 p2). In figure 1 the non-political and political framework conditions are sketched, but there is of course interaction between the two types of conditions. The figure is a way to show the complexity of the ICT development in Denmark. It is important to have these framework conditions in mind when discussing the shaping of the future development and use of ICT in Denmark. It is as well important to stress that the general development of ICT is a global process, and the big achievements in the general development of ICT are not taken place in Denmark. The technology development in Denmark is based on specialisation in adjustment of technologies and development of applications. The production of ICT in Denmark compared to the world is not that big, strong or advanced (Henten 2001 p. 11).

3.2.1.1 The characteristics of ICT in Denmark

98 percent of companies in Denmark (with more than 10 employees) had access to the Internet in 2002, and in 2004 83 percent of the population had access to the Internet. The export of ICT products has increased 44 percent from 1997 to 2003 and the export of ICT goods and services constituted around 7 billion Euros. In 2002 the ICT business stood for 28 percent of the total private investments in R&D, and 12.6 percent of new enterprises in 2001 was in the ICT business (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p. 5). The ICT effect in the Danish society is great and approximately one third of the Danish productivity growth is assumed to come from ICT investments and the use and integration of ICT (from 1988 to 2000) and around one twelfth of the employed are in the ICT business (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p. 3, 5 and 6).

The Ministry for Science, Technology and Innovation characterises the ICT sector in Denmark as having the following business and research related strength:

- A strong position in the communications technology (including mobile, wireless and optical communication)
- A strong position internationally in global ICT/pervasive computing with competencies in embedment, system integration and user-oriented design
- Denmark is one of the leading countries regarding the use of ICT by the citizens, business and the public sector.

(Ministeriet for Videnskab, Teknologi og Udvikling 2004 p. 3 & 5)

ICT has big impact on other technology areas as ICT often is a precondition for the development of other technologies. Figures from OECD show that companies using advanced ICT have increased productivity. Therefore it is very important to look at these areas when discussing the possibilities of ICT (e.g. biotechnology, where ICT is an important part of mapping the human genome), products (e.g. pumps) and services (e.g. self-medication) (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.6).

The Danish tradition for user participation in the development processes is important to keep integrated as a standard step of the development of ICT goods. User participation can secure that the development in ICT gives better possibilities for the single individual and a faster accept of the technology (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.10-11).

3.2.1.2 ICT research and development in Denmark

The ICT research and development has to a high degree been left to the private business in Denmark, which in 2001 constituted 90 percent of the total research and development within the ICT-area. Approximately the public investments in ICT research and development were 70 million Euros compared to the private investments on 600 million Euros. Public ICT investments constituted in 2002 a relatively low part compared to other investments and constituted around 4.8 percent of the total public investments. The latest big public research effort was the constitution of a research fund on 115 million in 2002 (the so-called UMTS-funds). With the establishment of the “højteknologifonden” (The high-technology foundation) a platform for an increased public effort on the ICT-sector is provided (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.7). The following paragraphs give a brief description of ICT research and innovation in Denmark.

Communication technology

There are research environments at Aalborg University (mobile and wireless communication technology and management of big amount of data). Aalborg University is project leader of an internationally research project on 4G-communication with 40 partners from Europa, Japan, Korea, and India. Siemens, Nokia, Ericsson and Motorola have R&D centres in Denmark. Another research centre is COM at DTU (optical communication) with cooperation with companies as Intel and Tellabs, which have placed R&D centres in Denmark. COM is involved in several European research projects. Cutting-edge competencies in internet protocols (IPV 6) and in wireless devices are present in Danish companies (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.11-12).

Software

A great part of the Danish companies in the ICT sector develops traditional software platforms. (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.12).

Pervasive computing

Katrinebjerg in Aarhus has a research environment that is based on a tight cooperation between research and business. The technologies are object orientation software programming and user oriented design. Aarhus University is project leader of a great European research project focusing on development of infrastructure for the future pervasive computing.
Danish companies as Danfoss, Grundfos and B&O are working with the pervasive computing technology.

Robot technology has a competency network – RoboCluster with around 70 companies and the Mærsk McKinney Møller Institute (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.12-13).

System understanding and integration

The strength in Denmark is based on good software development competencies and a relation between the technology and the contents and the international orientation and holistic approach in the Danish R&D culture. Especially in the communications sector the system understanding and integration in Denmark is unique and is the main reason why international companies have their R&D efforts in Denmark (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.13).

Security and privacy

In Denmark both research and industry are seen within this area. E.g. cryptomathic and encrypting researchers at Århus University (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.13-14).

Services

The vision of the Danish Ministry of Science Technology and Innovation includes a development from selling products to selling services. The traditional supply of products will change so that companies offer services instead through intelligent products. The intelligent products will gather data and transform them into useful information about e.g. conditions of the product and user behaviour. This could be supplemented by a feature, which warns a costumer when a product needs to have changed a part in order to prevent breakdowns (Ministeriet for Videnskab, Teknologi og Udvikling 2004 p.9).

3.2.1.3 The non-political initiatives

The market potential in Denmark is big as ICT is a fundamental part of the production and the society in general. The possibilities lie in the relationship between the development of new ICT products or applications and the ICT-intensive industries. The market is very developed with regard to penetration/use of ICT products and also with respect to quality requirements. The market is very diverse and depends on the characteristics of customers and end users and on supply of the components and products at the home market and the international market (Henten 2001 p. 15).

For Danish firms co-operation is important and e.g. electronic networks are a major part of the shaping and operation of these networks. Standards are another very important tool to make the co-operation possible and the co-operation is not only national. Industry locomotives do not exist in Denmark, but firms like Ericsson and Nokia influence the market and often the Danish firms have international owners. Denmark is known as a country with strong trade organisations, but in the ICT-area the trade organisations do not directly play such a big role. ITEK as an employers' and trade association (part of the organisation Danish Industry) is the only one dealing directly with ICT as a sector. The employees are members of lot of different trade unions depending on their job description. In the software part of the ICT-sector there is a trend as in the rest of the knowledge intensive sectors that employees do not want to be part of trade unions. The Danish equipment manufacturers act in an international market while the service suppliers act in a national market (Henten 2001 p. 21). As in other areas the labour costs in ICT area is high in Denmark due to the high tax burden, though prices on e.g. telecommunication is competitive compared to other countries (Henten 2001

p. 23-24). To some extent Denmark is in need of labour with very high specialisation, though there is no agreement about the demand (Henten 2001 p. 27). The role of entrepreneurs in the ICT area is low, but it seems that this tendency is changing (Henten 2001 p. 29-30). The availability of venture capital has historical been scarce but in the recent years there has not been a definite lack. Another way to raise capital for small companies in Denmark is to be acquired by a financially strong group of companies (Henten 2001 p. 32)

3.2.1.4 The political initiatives

The direct economical support to the ICT companies is marginal, but the Danish government is trying through education initiatives to cover the lack of qualified labour. Other ways the public sector Denmark is supporting the ICT sector is to demand high advanced solutions and finally by securing that other business areas demands ICT products and services (Henten 2001 p. 42). Most recently for example through the demand for electronic invoices from companies, which sell products and services to governmental authorities and institutions. The regulation has changed in Denmark as well in other European countries, but the deregulation of telecommunication sector was faster in Denmark compared to other European countries (Henten 2001 p. 50). EU is an important actor through the shaping of the overall framework regulation for the area and related areas as well. This includes directives for the handling of electronic and electrical waste (WEEE), energy consumption of products (EoP) and the use of hazardous substances (RoHS). The WTO is also a very important actor (Henten 2001 p. 52), most recently for example the discussions about intellectual property rights and about trade with information products and services (the TRIPS negotiations).

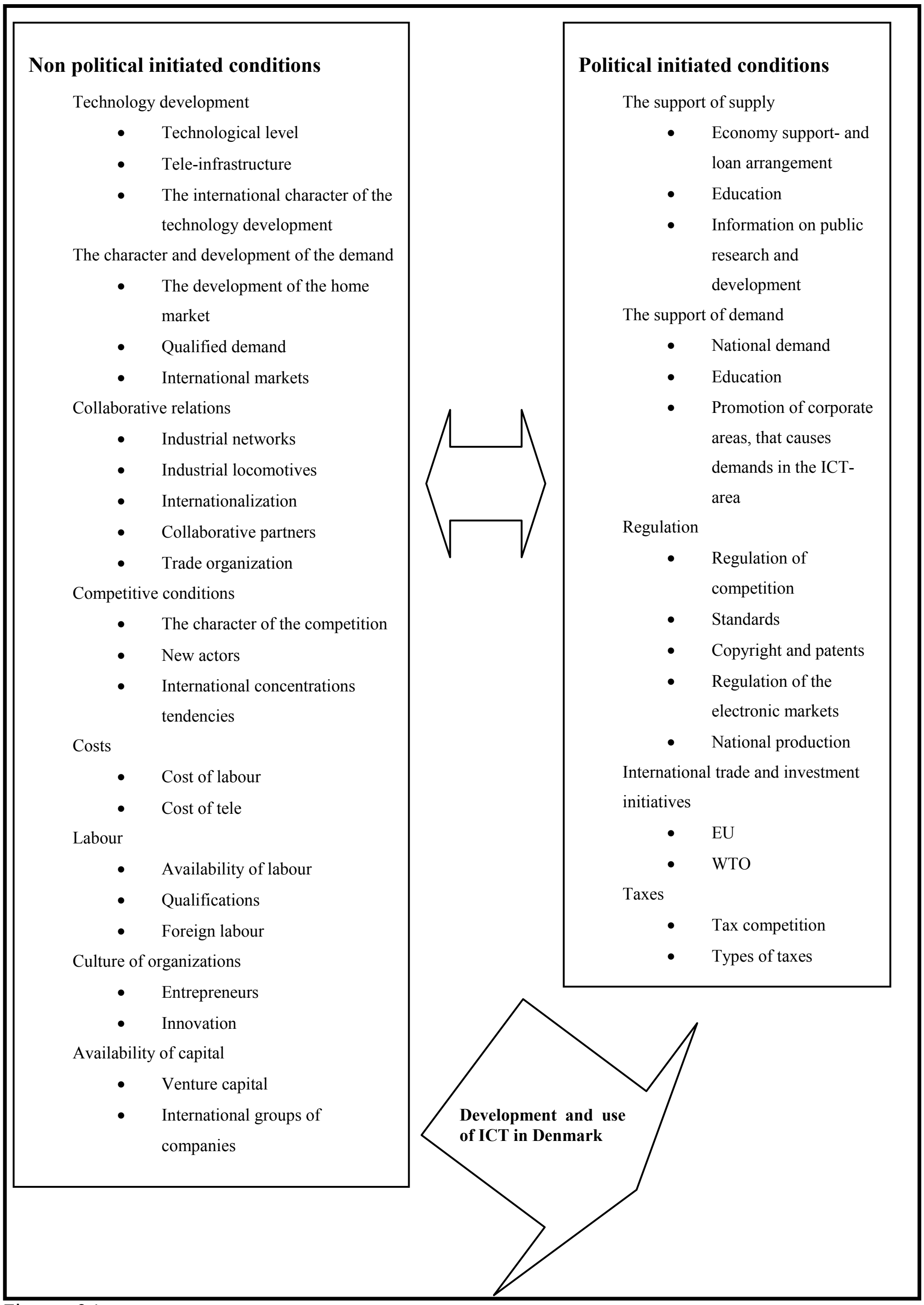


Figure 3.1
Sketching of the framework conditions on ICT in Denmark based on Henten (2001).

At the project workshop January 2004 about intelligent products and processes the issue about transforming findings from the research communities to use of companies in Denmark was addressed. The lack of Danish forums for demonstration of new technologies' possibilities was raised as an issue. The reasons are that Danish companies are too small to invest in technologies that are not proven to be profitable. As comparison participants referred to a greater will in the USA for demonstration of possibilities of new technologies. It was stressed that the challenge for Danish research and development is to transform knowledge into a level where companies can assess the usability. It was stressed that innovation in Denmark only can survive, if projects can be demonstrated as viable and are easy for Danish companies to make use of (Intelligent workshop group 1) and (Intelligent workshop group 2).

3.2.2 ICT as technology area

The FISTERA report describes European Technology Trajectories related to Intelligent Society Technologies (IST) which illustrates the technological areas of development of ICT in a social context. In the following these different trajectories are presented as an illustration of the complexity of the ICT development and the base of understanding ICT as a technology area (Saracco et al. 2004). These trajectories will develop in markets with different push and pull mechanisms that are very problematic to describe, but the dynamics of both the producers and users are very essential. Furthermore developments in surrounding technology areas influence the development of ICT trajectories. The understanding of the future ICT has often been characterised as being very optimistic and hyped. ICT can be understood by splitting it up in different layers, the technical layer, the functionally layer, the service layer and the ambient layer within the technological trajectories. Another important dynamic of the future ICT development is the disruptions that these trajectories might create at existing markets (Saracco et al. 2004 p.13).

The technical layer is the technical specifications that are relevant for different types of ICT. Some new technologies will be based on the further development of existing technologies in the ICT trajectories. The relationships between different technologies within the ICT are very important and they are often depending on each other as well as on surrounding technologies (Saracco et al. 2004 p.13).

The functionality layer represents the functional properties of ICT's by focussing on their technical aspects. The functionality layer is crucial because it presents a base for the decision of where and when to invest in the basic technologies and building blocks for the ICT field. The functionality could be provided by various technologies from the technology layer, which means that the specific technologies could be competing with each other and some technologies will in the future potentially be outcompeted by others with the same functionality (Saracco et al. 2004 p.13-14).

The services layer is the actors and the market segment (size and expenditure capacity) as it is and the expected development. Factors as cost of components, of packaging, of delivery and operation are essential. One of the central issues is multi-users or temporary property of products such as car sharing as an example on a relative new service. The marketing drive often pushes for bundling of functionalities to get a better market position, which not always is what customers need, though they might have a perception of needing it. Some niches are going the other way and are offering specific products with specific functionalities of services. The relationship between functionality and service is of course of high importance and is describing the connection of what technology can provide and what the market wants (Saracco et al. 2004 p.14).

The ambient layer is the physical and the virtual places where technologies are in action, through the services they enable, and where the various actors (end users and providers) are interacting with each other.

3.2.2.1 *Technical trajectories at functionality level*

The trajectories that are identified for ICT have been developed by focussing on the functionality of the involved technologies and their technical properties. Consequently it does not present or focus on specific technologies within ICT nor does it identify the social and environmental context in which applications operate. In opposite the trajectories could contain various technologies competing or complementary, but still defining some basic material and functional properties these have in common. The trajectories are:

- Bandwidth trajectory
- Communications trajectory
- Data capturing trajectory
- Human interfacing trajectory
- Information display trajectory
- Information retrieval trajectory
- Pin pointing trajectory
- Printing trajectory
- Processing trajectory
- Storage trajectory

Bandwidth is the transmission capacity at the access level and it's expected that in the next 5 years there will be a deployment of xDSL (modulation schemes to pack data onto copper wires) and optical fibres. For the next decades the race of speed will continue, but will gradually turn towards bandwidth guarantee and –flexibility. It is supposed that the 100 mbps bandwidth will satisfy the most common demands, and research for higher speed will be done only related to specific applications like holographic projection, grid services etc, which will in some way affect general infrastructure and applications (Saracco et al. 2004 p.17).

In the last 30 years the communications technology has developed dramatically mostly focusing on simplification in the communication across the world. The next step will be the emergence of wireless networks and possibly the solution of the interface problem through inter-terminal communication. This may lead to a significant increase in the wireless bandwidth with a radical change in the way of communicating. This is not something that will happen by itself but needs research and investment and a vision to guide the direction (Saracco et al. 2004 p. 17).

Data capturing has evolved constantly the past decades but through the development of smaller, cheaper and simple sensors, satellite surveys, web cams, personal recording devices the quantity and quality these will change. Technologies as electronics, bioelectronics, nanotechnologies, MEMS (micro-electro-mechanical systems with an integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate), communication technologies, fabrication processes (including letting analogue, digital and RF (radio frequency) circuits on one chip) will participate in this development and the security area is seen as a main driving force. Especially the possibility of a variety of cheaper amount of sensors is seen as essential in the development of data capturing (Saracco et al. 2004 p. 17).

Human interfacing is affective computers, which can customize the communication to the actual mood of the user and will be used for the computer to understand the special interplay between individuals, which is not a possibility to day. The communication will be based on understanding instead of formalised commands. Artificial intelligence, agents based dialogues and many others will be part of this evolution both as driver and as barrier (Saracco et al. 2004 p. 18).

The development in new **Information display** may be crucial for several sectors as design, medicine and entertainment and is based on both fixed and mobile displays. It is supposed that the 2D technology will have the majority for the next 15 years, but the 3D technology will also evolve the next 5-8 years in different niches and in the next decade it will become more and more common (Saracco et al. 2004 p. 18).

Information retrieval is in a high growth and it is expected that the amount of data that are collected will be doubling every two or three years for the next 20 years. Going from data to information will be one of the great tasks for the next decades and a lot of technology innovations are needed to secure this transformation (Saracco et al. 2004 p. 18).

Pin pointing technologies by tagging, beacons and satellites will be common at the end of the next decade and already by 2008 most products will have a tag. The next step will be tags integrated in services and in information. The barriers will be problems with security and privacy, but it is supposed that these problems will be overcome. The tagged society is predicted to integrate the information technology with medicine and biology (Saracco et al. 2004 p. 18-19).

Printing is one of the technology areas which has evolved significant and will do so in the next decades. Printers will around 2015 be embedded in objects or the printer embedded in the printing materials. The evolution could contain the possibility to print 3D images or biological materials as human tissue. From 2010 printing will be able in interaction with the user and to upgrade itself. By 2020 the technology will be to print whole objects instead of today's use of drops of ink (Saracco et al. 2004 p. 19).

Processing has been evolved by doubling every 18 month[3] in the last 30 years. This trend will continue because of the demand for decreases in fixed costs through higher volume production and squeezed size on the products, which will demand higher processing. By 2020 it is supposed that every object will have a processing capability embedded (Saracco et al. 2004 p. 19).

Storage has been doubling every year the last 10 years, with a decreased price on 10 % as a result with an introduction of new storage technologies every 10 years (floppy to diskette to CD-rom and so forth) and holographic disk based on thin polymer as the new technology for the next decade. The shifts in technology have a great impact on the whole sphere of the industries. There is no sign on slowing down the evolution or decrease in price. The development of capacity will make it possible to store so much information that local virtual internets will be possible to create and everything will be recordable with enabling new services and maybe industries. By 2020 the storage will not be a limiting factor (Saracco et al. 2004 p. 18).

[3] Moores Law.

3.2.2.2 Areas of ICT application

Several researchers try to illustrate the complexity of the application of ICT by reducing the amount of applications by putting them together in overall application fields that together attempt to contain all specific applications. Wunnik et al point to the following fields of application as environmentally important, which means that ICT could imply positive and/or negative changes in the environment impact (Wunnik et al 2004 p. 559):

- ICT-industry: Manufacturing and services.
- ICT use: Entertainment, communication, data processing and home network.
- E-business: E-commerce plus e-based and/or e-supported activities.
- Virtual mobility: Telework, virtual meetings and teleshopping.
- Virtual goods, which refers to the dematerialisation potential of ICT goods.
- Waste management: ICT waste, effect of virtual goods and demand for packaging.
- Intelligent transport systems: Control and guidance, road pricing, parking, assistance, freight and fleet control and management.
- Energy supply, fostering renewable and Green House Gas and liberalised electricity markets.
- Facility management: Space heating, water heating, cooling, lightning, cooking end electric appliances.
- Production process management used to increase production yield and to minimise energy demand.

Such a division of applications will surely cut off some applications, but having in mind that ICT is so incorporated in all aspects of the western society, it is very important to somehow make a base for the illustration of the huge applications of ICT.

3.2.2.3 Possible future disruptions in the ICT development

The possible disruptions earlier mentioned are important to assess because they describe possible decisive technological shifts and thereby functionalities and services and finally the adoption of ICT that disrupt markets as they are known. New actors have the opportunity to be enrolled in the markets and disruptions can create brand new markets by transforming mature businesses into new ones. It makes the evolution spin once more, where new technologies in new markets are attached to a brand new set of rules. The assessment of these disruptions is focusing on why and how, instead of when and what may occur. The disruptions can be addressed by technological enabling factors, market driven factors, industry impact, market sectors affected and likeliness to happen (Saracco et al. 2004 p.152).

The accessibility of central management (because distribution centres is becoming easier together with cheaper and cheaper technologies) is enabling the transformation of products into services. An example would be that instead of selling hardware companies turn to give hardware for free to their clients that enable services also provided from the company (Saracco et al. 2004 p.153). (A parallel example of this today, are mobile phones that are sold for 1 DKK, with a contract on the service “calling and other features” that are unbreakable for six months).

This trend in more and more integrated and distributed software based services and less visible and smaller – even miniaturised – products and computer equipments will include some of the following developments:

- The disappearance of the computer
- Ubiquitous seamless connectivity
- Changing traffic patterns
- Disposable products
- Autonomous systems
- From content to packaging
- The emergence of virtual infrastructures

The disappearance of the computer is already in progress. A lot of micro processors are embedded in other devices such as remote controls, microwave ovens etc. This tendency is predicted to increase significantly, supplemented with computers embedded in devices that seamless will interconnect with a lot of displays attached in televisions, watches, mobile phones etc. The PC will be integrated into various devices that interconnect with each other. At the same time the appearance of storage, processing, sensing and communicating in every day objects will create new possible services for these objects (Saracco et al. 2004 p.156).

Ubiquitous seamless connectivity is the trend of a shift in connectivity. Connectivity by a fixed line will probably to some extent shift to a cable free technology but in general the connectivity will increase. Pervasive computing will be a big part of this development. The ubiquitous connectivity in general will likely increase the amount of services offered and it will result in a general increase of competitiveness (Saracco et al. 2004 p.156).

To day the information traffic is often fixed to a higher download speed than the uploading, but it is expected that in the future that a more open traffic will be needed and changing traffic patterns will occur. The need to upload and download increased amounts of data e.g. digital photos, calls upon more flexible traffic and not fixed as today. Furthermore changes in the disappearing computer will need a 24hour connection and network solution that is not fixed but is flexible and possible to change locally (Saracco et al. 2004 p.157-158).

The productivity and the possibilities of printing products locally will increase the amount of disposable products. The advantage of disposal products is that they can be customized in a higher degree than products produced in the industry but the lifetime of such products is suspected to be somewhat shorter than products known today. With all of these disposable products, problems will probably occur in the recycling phase (Saracco et al. 2004 p.156-161).
It is supposed that systems will be able to take local decisions that will affect other local decisions by mimicking living organism without been connected to a central control system. These systems will be more responsive and be better to fit to a changing environment and approach the issue of interoperability in a new way on a new level resulting in autonomous systems (Saracco et al. 2004 p. 162).

The production of information content is supposed to double every three years and the relationship between customers and products is changing. The way of packaging the products are becoming more and more decisive for the success of the products and the connected services. The packaging technologies are expected to be developed in the future and will be a part of the competitiveness of a broad range of industries going **from content to packaging** (Saracco et al. 2004 p.164)

In future it will be possible for local resources to plan different services or events and using well known and well trusted organisations as their presenter and **emergence of virtual infrastructures** will be possible. This could be entertainment performed by locals and backed up by a professional company by a virtual presentation. This will mean that organisations will have greater possibilities to present their products all over the world relatively simple, cheap and with a minor effort. Local or country-wide businesses will be challenged by multinational businesses across the world (Saracco et al. 2004 p.165-166).

3.3 ICT and the environment

The relationship between ICT and the environmental aspects and impacts of these technologies are not fully understood, and the literature maintains typically a rather general and idealised view of the relationship and is often not capable of analysing the complexity of the ICT technologies and their applications. These limitations may be due to the fact that most discussions tend to describe the relationship at a rather generalised level, where the specificities of both technology and the conditions for its use and impacts are not clearly understood. The main focus in most research is anyhow placed on the overall impact of ICT on the economy and on societal changes in general, which then in some cases is related to the environmental impacts of these broader economic and social changes and transformations. Despite this lack of detailed understanding of the environmental impacts of ICT, these technologies are very often identified as having important contributions to developments that will eventually provide the base for decoupling the economy growth from environmental degradation (Ryan 2004 p.63).

The environmental aspects are most often not included or considered as an issue in technical and social innovations. The literature is in contrary describing issues like ICT and the relationship to e.g. process optimization, the use of consumer products, new features and functional possibilities, and relations to international standards mostly from a techno-centric point of view including aspects of economic and social impacts of the technology. The very few studies of the relationship between environmental aspects and ICT are provided by scientists typically not enrolled in the ICT complex. This view is supported by the fact that the literature search of this report only found a few hits including environmental aspects, compared to the thousands of hits addressing technical issues of ICT's. Also the chemical aspects relating to the use and impact of ICT are as well not frequently addressed. The tendency, though, is showing a gradual change in the recent years where more of the identified articles include environmental aspects of ICT's and more often addresses – at least by wording – questions of the role of ICT's in relation to sustainability issues. This is also stressed by the Eco Lab 03 report (Ryan 2004 p. 65) and in Berkhout & Hertins report to the OECD (2001), which have made an important contribution to this part of the research.

Many reports describe a nearly automatic effect of increased use of ICT as a reduction of the resource consumption in society, because ICT is based upon handling of information instead of physical materials. The problem with such a statement is that the environmental impact resulting from the development and use of ICT is not analyzed in details, but only at a very general and even speculative level. The research is not looking into the impact of ICT on more specific economic and social processes and the impact of such changes on environmental impact from resource consumption and wastes and emissions. It is often claimed that the industrialised societies have been able to reduce their use of some resources during the same period as the strong development of ICT and the industrialised societies are often named as ‘knowledge societies’, knowledge economies’ or ‘information societies’. It is, however, important to be aware that the reduction in the industrial countries’ use of some resources since the ICT-application started to accelerate could be the result of quite straightforward economic measures to reduce materials cost and make processes more efficient in combination with a parallel relocation of a part of the resource intensive industries to developing countries (ex. textile, iron and steel, manufacturing, and electronics industry). Also the often presented idea of ICT’s substituting the need for transportation and mobility need to be studied more in detail to show evidence at a larger scale. The model in these assumed positive impacts of the use of ICT is taking from the idea of new technologies being more efficient and substituting older technologies. In the case of ICT another model seem to show as much relevance: the parallel growth in the use of ICT’s and the demand for other material goods, transportation and even more mobility. In this sense, the use of ICT is not just a question of monitoring, controlling, communicating, and processing information in more efficient ways, but also an independent enabler of new patterns of consumption, production and mobility.

Few reports like (Berkhout & Hertin, 2001) and (Ryan 2004) come up with some more detailed and complex perception of the relationship between ICT and the environment and do not see this automatic greening of society from the use of ICT. Ryan (2004) explains that since ICT is used to handle information it is important which information the technology is provided to work with and which control mechanisms in companies and public regulation etc. which determine the use of the technologies and the information. Globally seen, there is a general need for further research and monitoring of the ICT environmental impacts (Matthews 2003 p.1765) and in general the few research reports available are very critical about the possible environmental positive impact from the use of ICT. In the development of ICT no automatic mechanism or driving force seems to exist taking the environmental aspect into consideration. The perspective in the article by Matthews is very pessimistic about the ability of ICT innovations to include environment as an important parameter. This includes the development of equipment, production technology and processes. In general this research emphasises that regulation of the area is necessary. Furthermore the area is seen as having a very deterministic approach and seems to be convinced that the technology progress will be the solution for any problems that might occur either generated from the technology itself of by the actors around it. An example of this is the constant replication of the belief in and the seeking of fulfilling Moore’s law, which in effect does not address the overall efficiency of ICT usage but only the handling of simple data (Berkhout & Hertin 2001). This is sometimes mentioned as an example of the dramatic expansion of ICT efficiency, but does not relate to the other side of this development, that more and more processes – earlier not involving ICT at all – now are affected by and include ICT due to the constantly reduced costs of applying ICT’s. Ryan sees the general the development of ICT as driven by the search for better output, efficiency, new types of usage, and usability. He claims that the environmental aspects seldom are seen as a self-contained driving force, though the use of ICT in product design sometimes is used for the development of lighter products with the use of less material and thereby some potential environmental benefits. But as a technology, which not by itself is based on material processes and transforms energy as a primary purpose for direct use, the environmental aspects of ICT's include all possible types of environmental problems in relation to the production and/or consumption processes the ICT application is involved with. No known environmental problem can therefore be seen as not influenced by ICT, while at the same time, the direct impact of ICT's today shows the growing need to regulate the tremendous growth in electronic – often even non-recyclable and toxic – waste to which ICT brings a larger and larger part.

The relationship between ICT and the environment can be illustrated by ordering the impacts at three different levels, presented in the following. The definition of these three levels of environmental impacts is based on the studies of Berkhout & Hertin (2001), Ryan (2004) and Wunnik et al (2004).

First order relationships between ICT and the environment are the direct environmental impact from the ICT equipment and ICT infrastructure, i.e. the use of resources and the environmental impact from manufacture, operation, and disposal of ICT equipment and infrastructure.

Second order relationships between ICT and the environment are the environmental impacts related to the use of ICT within different areas of application. These relations are the most important concerning the potential substitution of other processes stressing the environment, and improving the efficiency of production processes etc. Some of these applications are environmental oriented applications as monitoring of a certain environmental issue or process regulation with e.g. focus on reduction of energy or material consumption. Most applications, however, are not developed with emphasis on their environmental aspects, and as already mentioned some of the environmental impacts are quite complex to assess.

Third order relationships between ICT and environment are the consequences of changes in the societies' total use of resources through changes in the magnitude of different business and product areas. This type of impact is represented in the possible parallel growth in e.g. the access to information and the consumption of material goods and transportation. This level of impact also includes social and structural changes in production and consumption resulting from the implementation of ICT's almost everywhere. Table 3.1 elaborates the three levels of relationships between ICT and environment further and present those areas of application, which are analysed in details later in the chapter. They have been chosen based on (Berkhout & Hertin, 2001), (Ryan, 2004) and (Wunnik et al, (2004), interviews with Danish stakeholders and the project workshops.

Table 3.1.
Framework for the assessment of the relationships between ICT and environment (inspired by (Berkhout & Hertin, 2001, Ryan 2004 p.64, Wunnik et al 2004 p.560)).

Order	Possible relationships between ICT and the environment
First order relationships Direct environmental impacts related to the ICT equipment and ICT-infra structure	The environmental impact related to the ICT equipment and ICT-infra structure: The environmental load can be lowered by reduction of the amount of heavy metals in components, a lower level in use of energy in components and equipment and a higher level of reuse of components and equipment. The environmental impact could be increased by the constant discarding of products due to constant changes in functionality, a more disperse spreading of sensors in the environment etc.
Second order relationships Environmental impacts related to the use of ICT and its influence on processes, products etc.	Applications can have environmental aspects as focus or could have unintended positive or negative environmental impact. Some important areas of application are • Improving environmental knowledge • Design of products and processes • Process regulation and control • Intelligent products and applications • Transport, logistics and mobility A dematerialization of the economy could happen – i.e. a relative decoupling of the relationship between economic growth and use of resources, but new generations of ICT-products could also result in a bigger pool of electronic products with an increase in use of resources. This will counter the decoupling.
Third order relationships Environmental impacts from societal changes among consumption areas	An easier access to information about the environmental performance of products could imply a lifestyle change with increased demand for more green products, but a "rebound effect" could occur. For example a bigger pool of electronic products due to lower prices on electronic products, or increased transport due to the increased electronic communication between people from different nations through e-mails, parallel with decreased prices on air flights.

Wunnik et al have used computer simulations to predict the impacts on the environment from the future ICT and compared them with a so called ICT freeze situation, where the applications of ICT remain the same level as in 2000. The results are not that straightforward. Total freight transport, total passenger transport, share of renewable energy in electricity (RES) and the amount of waste not recycled are predicted to increase by the development of ICT. On the other hand the private car transport, total energy consumption and total greenhouse gas (GHG) emissions are predicted to decrease. The results presented by Wunnik et al. show that the overall impact on the chosen indicators may vary between approximately -20 and +30 %. Wunnik et al do not see these figures as the most important result from their study, but the fact that the application of ICT's is a constant battle to avoid further negative impacts on the environment, and definitely not a very important contribution of its own to solving the environmental problems of contemporary society. It is claimed that it is necessary to find ways of promoting the environmentally positive aspects and inhibiting the negative ones (Wunnik et al 2004 p.560).

3.3.1 Environmental impact related to ICT-equipment and –infrastructure

This section looks at the first order effects related to ICT-equipment and ICT-infrastructure. The section is structured along the overall life cycle phases of a product, which are extraction and manufacturing of raw materials, manufacturing of components and products, use of the ICT product, disposal and transport.

The first order impacts cover environmental impacts in terms of e.g. global warming, acidification, nutrient enrichment and effects from emission of toxic substances. Another important impact related to the life cycle of ICT products is the depletion of the scarce resources, which are essential to manufacturing of electrical and electronic equipment.

3.3.1.1 Extraction and manufacturing of raw materials

The most important raw materials used for manufacturing electrical and electronic equipment are (Kuehr et. al. 2003) and (Blum 1996):

Table 3.2.
Important raw materials applied in the manufacturing of electrical and electronic equipment.

Resource	Raw material	Typical applications
Iron ore	Iron and steel	Housing and construction parts
Mineral oil and natural gas	Plastics and chemicals	Printed circuit boards. Housing and construction parts. Components.
Aluminium ore	Aluminium	Housing and construction parts. Components.
Sand and chalk	Glass	Screens. Components.
Sand	Silicon	Wafers for chips
Copper ore	Copper	Cables. Printed circuit boards. Components.
Tin ore	Tin	Solder. Printed circuit boards. Components
Lead ore	Lead	Solder. Printed circuit boards. Components. Glass in screens.
Ores of precious metals	Silver, gold, platinum etc.	Chips

Manufacturing of raw materials requires energy to extract e.g. copper from the copper ore. This process will inevitable also leave a great deal of waste material behind and it may cause serious environmental impacts in the form of local pollution of soil and water depending on the conditions and precautions taken at the specific mining site.

Some of the raw materials essential to modern electronics like copper, tin, silver, gold and platinum are based on scarce resources. That a resource is scarce means that the known deposits of the respective ores that are economically profitable will only last for a short period of time. Examples of supply horizons for some relevant resources are shown in table 3.3.

Table 3.3.
Supply Horizons for selected metals (Hauschild, 1998).

Resource	Supply Horizon (Years)
Lead	20
Tin	27
Nickel	50
Copper	36

This does not necessarily mean that the resources will be used up after this number of years, but it indicates that the price will rise along with a reduced amount of these raw materials and the rising costs for exploitation. This will most certainly also imply an increase in the energy consumption along with other environmental impacts caused by the exploitation.

The most important trend in the use of raw materials for ICT products seems to be the phase out of lead due to the RoHS directive (RoHS 2003), which demands that new electrical and electronic equipment put on the market should not (among others) contain lead. Lead will typically be substituted by tin or alloys of tin, silver, copper and/or bismuth (STMicro 2004) and (Ascencio 2004). Other trends are focussing on the phase-out of brominated flame retardants – not just PBB and PBDE which are covered by the RoHS directive, but also brominated flame retardants in general (Electronics goes green 2004). Research about alternative materials for printed wiring boards (PWB) based on renewable resources (lignin) and thermoplastics has been initiated (Electronics goes green 2004). The environmental improvements might be obtained because recycling is made possible and the application of brominated flame retardants can be eliminated. The "New Materials" session at the Electronics goes green 2004+ conference did not disclose any indications of other decisive trends in the application of raw materials for electrical and electronic equipment (Electronics goes green 2004).

3.3.1.2 Manufacturing of components and products

ICT-products constitute a significant part of the GDP of most industrialised countries and it is still a growing field. Also the amount of ICT-equipment is quite big and increasing. The environmental impacts of the manufacturing of these goods include emissions to air and water of heavy metals and solvents and other substances that are carcinogenic and/or neurotoxic. In the recent years some environmental impacts related to the manufacturing have decreased per produced unit through process management and substitution of some hazardous materials. However, of the materials used in the manufacturing of ICT-equipment only two percent ends up in the product itself (Berkhout & Hertin 2001 p. 7-8).

For some of the more vital parts of an ICT product the waste ratio is even higher. The manufacturing of a 2 g chip implies the use of 970 g of fossil fuel and 72 g of chemical substances which is approx. 500 times the mass of the chip (Kuehr 2003). Miniaturization of components and in some cases also products does not necessarily imply a decrease in the use of materials – in some cases the reverse is the case, as the miniaturization can require a higher purity of the production processes and the materials, which increases the demand to the materials and increases the amount of waste (Ryan 2004, p. 125).

The systematic application of ecodesign as an integrated part of the product development procedure will probably decrease the environmental impacts measured per functional unit (Ong 2004) and (Pascual 2004). However the functional unit is constantly expanding. E.g. 7-10 years ago a mobile phone was just a phone. Today it is still called a "mobile phone" though it is hard to find a device which is not also a (video) camera, a calendar, a notebook, a game boy, mp3 player etc. This extended functionality of the mobile phone means an increase in consumption of materials and energy (Legarth 2002). The introduction of multifunctional products like the mobile phone does not seem to reduce the demand for e.g. digital cameras or mp3 players (BFE 2005).

This trend also applies to other ICT product groups where the functionality of "the typical mainstream product" is continuously expanding. Intel predicts that a processor in 2015 will pack 20 to 30 billion (10^9) transistors pr. square inch (Ramanathan 2005). The development seems to continue and opens up to new applications that have been enabled by the increased computer power. The environmental improvements, which have taken place, have thus been overtaken by the increase in functionality (and the number of products as mentioned above). Furthermore, the environmental improvements are not a result of a demand for "green products" as this does not exist among customers or regulatory authorities (Stevels 2004 & Campino 2004).

3.3.1.3 Use of ICT products

Despite numerous attempts of decreasing the energy use during the use of ICT-products, the aforementioned development of the number of products used and the development of the product functionality undermine these efforts (Berkhout & Hertin 2001 p. 8). The operation of the ICT-infrastructure is estimated to account for 3-4 % of the use of energy in the industrialised countries (Ryan 2004, p.125). Set-top boxes (integrated receiver decoders) are projected to add some 6,000 GWh of power demand in the UK by 2010 (Berkhout & Hertin 2001 p. 8).

Of the total environmental impact over the life cycle of an ICT product 50 to 85% is estimated to be due to the energy consumption in the use phase (Stevels 2004). It is thus worth while to have a closer look at the nature of this power consumption.

The energy consumption of an ICT product can often be divided into three states (Elsparefonden 2004):
On Mode/Active Power is the state where the device is active and carrying out its primary function. This could be when the user watches TV, talks on the phone, writes on the pc etc.
Sleep Mode/Low Power is the state when the device is not active but ready to respond to signals from the user or another system. This could be when the TV is ready to respond to a signal from the remote control, the mobile phone is ready to respond to an incoming call, the printer is ready to receive a file for printing etc. In this state the ICT product will usually operate at reduced power consumption.
Off Mode/Standby Power is the state when the device is switched off by the user but it is still connected to the power outlet. Many ICT products will also have electricity consumption in this state. This might be because there is a clock to "keep alive" or the stored TV-channels will be lost if the power is switched off.

As many devices like e.g. computers, fax machines, TVs and videos might spent almost 24 hours a day in either the Sleep mode or the Off mode there is a huge potential for improvements and it is possible to manufacture products that can cope with tough requirements to the energy consumption (Miljømærkesekretariatet). The standby losses in households were already in 1998 estimated by IEA to account for 5-15% of the residential energy use (Berkhout & Hertin 2001 p. 8). Recent estimates say that in Denmark half of the energy consumption for running TVs, videos and PCs is used for standby or sleep modes, where the devices are not actively being used. This corresponds to approx. 10% of the energy consumption for private households (Elsparefonden 2005). This issue is addressed by different regulatory initiatives, including incentives (Elsparefonden 2004) and (EuP directive proposal 2003).

The density of transistors has now reached a level where the energy consumption related to the operation of the processor has reached a level, where it is realised by main semiconductor manufacturers that it is necessary to reduce the energy consumption in order to maintain a proper and reliable function of their products (Ramanathan 2005):

> *"Currently, every one percent improvement in processor performance brings a three percent increase in power consumption. This is because, as transistors shrink and more are packed into smaller space, and as clock frequencies increase, the leakage current likewise increases, driving up heat and power inefficiency. If transistor density continues to increase at present rates without improvements in power management, by 2015 microprocessors will consume tens of thousands of watts per square centimetre."*

Low energy consuming ICT products only implies savings to the customer, who has so far only demonstrated a very modest interest, and thus left no incentive behind for the manufacturer to develop such products. An exception to this general trend are some public purchasers (Elsparefonden 2004) who have uncovered potential savings by using PCs and other equipment that deal with energy in a more responsible way. It should be born in mind that development of real low energy consuming equipment like laptop computers, LCD screens, mobile phones, portable "music machines" etc. all have been driven by the demand to the functionality and not by the intention to reduce the power consumption itself.

The increasing number of products and the ever expanding functionality of what is considered an average main stream ICT product (as mentioned in the previous section) is seriously contributing to an increase in the energy consumption in the use phase and will probably outdo those improvements that might be a result of the development of the technology and future regulatory initiatives.

For another product group related to ICT, the development has been somewhat different. The market for refrigerators and freezers in the EU has been covered by an energy labelling framework (Directive 2003/66/EC), where the products are labelled according to their energy consumption. In Denmark in 2004 the sales in the best category (A+ & A++) was 60% (Hvidevarepriser.dk 2005). The reason for this success seems to consist of:

- The future implementation of the common EU framework giving the manufacturers an incentive to develop low energy consumption technology (the EuP framework directive (directive for Energy using Products)) which is analysed further in paragraph 3.3.2.3)

- It is economically beneficial for the consumer to invest in a low energy consumption product

- A well organised campaign supported by the Danish authorities also focussing on the economic benefits for the consumer and paying a discount when buying a energy efficient piece of equipment

Whether similar success would be possible for ICT products is hard to predict. Regarding especially consumer electronics the decision of purchase is probably more driven by fashion and "what is cool" as the purchase of for example a freezer is more based on common sense. For ICT products used in the infrastructure (servers, telecommunication equipment etc.) the most important issue is reliable operation and any environmental improvements that might just slightly intimidate the reliability, will probably be difficult to sell.

3.3.1.4 *Disposal*

The speed of development and adjustment of products in the ICT sector and products containing ICT-components is often extremely high as the performance, memory and the transmission of data is constantly increasing (Berkhout & Hertin 2001 p. 9). Many products are disposed of as they still possess their full functionality simply because expanding performance and functionality is presented to the customer in the shape of new products (Erichsen & Willum 2003). The effect of this rapid innovation is an extremely high turnover of hardware and software which result in an increased amount of electronic waste. The waste includes electronics with copper, lead, mercury, flame retardants and plastic softeners (Berkhout & Hertin 2001 p. 8). It is a prioritised area within EU with, as earlier mentioned, several directives in operation or preparation (Ryan 2004 p.124) and (Berkhout & Hertin 2001 p. 8). A result of this focus is the WEEE directive (Waste from Electrical and Electronic Equipment) (WEEE directive 2003), which reflects an ambition to deal with the issue of the increasing amount of waste electrical and electronic equipment. The directive is discussed later in this chapter.

The reuse of most ICT equipment (meaning e.g. the reuse of components) is minimal (Renner 2004), although some reuse of PC's has been organised as projects aiming at supplying PC's to poorer countries. The recycling of ICT (meaning e.g. re-melting and extraction of metals) is a well established activity in many countries supported by an efficient infrastructure and legislation (Danish legislation 1998) and (Swedish directive 2000). Especially the extraction of precious metals from waste electrical and electronic equipment is quite effective (Busch 2003).

3.3.1.5 *Transport*

The production of the ICT-components and products is often organised in globally extended supply chains, which implies a high use of energy for distribution. A typical PC contains 1500-2000 components sourced from around the world, and typically transported by air. The complexity and scale of the global electronics sector means that the aggregate environmental impacts of the supply chains are large (Berkhout & Hertin 2001 p. 8). Furthermore an increasing number of products are assembled far from the regions where they are marketed. Both trends are increasing and imply an increasing environmental impact due to transport of raw materials, components, subassemblies and end-user products. There is also the risk that the waste handling and waste water treatment is of a poorer quality in the countries outside Europe, where most of the manufacturing takes place. This means that not only has the environmental impact from the manufacturing of the ICT products for the Western countries been moved outside these countries the impact has probably also increased due to the mentioned poorer environmental infrastructure.

3.3.2 European Environmental legislation concerning electronic and electrical equipment

3.3.2.1 *Directive on Waste Electrical and Electronic Equipment – WEEE*

The main topics of the directive are:

- Specifies collection requirements and targets in the member states
- Specifies recycling targets for different product categories
- Introduces producer responsibility for the disposal costs

- Electrical and electronic equipment shall be marked, telling the consumer not to dispose it with normal waste stream

The producers of EE-equipment must provide information to recyclers and it should be implemented in national legislation by August 2005, but in Denmark it is implemented 1 January 2006 (Ecodesign 2005) and (Con. Grau MST 2005). The directive is relatively clear on which forms of WEEE that are included. All electrical and electronic equipment from households and from the industry is divided into equipment groups. The directive is quite clear on which substances that have to be handled separately and in amount in kilos it is approximately the double of the amount today (Con. Grau MST 2005).

The handling including collection and disposal of the waste generated is in Denmark delegated to the Danish municipalities. The general principle of the Danish implementation of WEEE (after public hearings) is that the simple waste handling should be minimized and the recycling and reuse should increase. Based on the polluter pays principle (formulated in the directive) the producers or those who import the products will play a key role and will be accounted for the environmental impact in the after-use phase with the reprocessing as another key factor. The system will be functioning in two separate systems, the municipal based and a private based (Braun & Dirckinck-Holmfeld 2005 p. 7). The private based system will handle the industrial WEEE, while the municipal based collects the household WEEE and gather it at recycling stations, where the producers must take over. The municipalities or consumers will keep the expenses from the collection of the household waste (Con. Grau MST 2005).

On the top a non-profit organisation will be formed with the responsibility for registration of producers, their amount and different types of products put on the market. They will certify and check the waste managers and third party organisers, as well as providing the Danish environmental protection agency with statistical information (Braun & Dirckinck-Holmfeld 2005 p. 7). The handling of industrial WEEE will probably require and include a number of more practical units as supplement to the overall administrative organisation. These third party operators will manage the logistic issues related to the waste management. These issues could be contracts with producers, contacts with different contractors and contracts with companies responsible of reprocessing and other treatments. The implementation proposal contains a segment of competition, which should facilitate innovation with increased recovery and decreasing costs (Braun & Dirckinck-Holmfeld 2005 p. 7-8).

Another alternative allowed is that producers organise their own take back system. This will require a bank guarantee for the overall organisation if anything should go wrong (Braun & Dirckinck-Holmfeld 2005 p. 8). Regarding the specific handling of the WEEE the Danish EPA will describe what the producers must do and which fractions the handling will give. The producers are left alone in setting up the necessary processes to do so. Most of the new required processes are disassembly, which will be done manually and are very easy for existing companies to do and does not require big investments (Con. Grau MST 2005).

Regarding the household waste the implementation of the directive will open the existing system in a way so that every private provider with a waste manager certificate can bid on a task. In Denmark the municipalities have had monopoly on the waste management from households. The payment structure of the municipal system will be changed so that the producers instead of the consumers will held the economic costs in compliance with the directive. This is done through payment according to market share (calculated by kg or parts sold). Finally the minister of environment can prohibit certain products, which are designed without possible reuse, and the producer must provide information to the waste manager for reprocessing of the product within a year of the marketing date (Braun & Dirckinck-Holmfeld 2005 p. 8).

As this directive is being implemented into national legislation in all 25 EU member countries it is supposed to cause:

- Reduction of the environmental impact due to pollution caused by irregular treatment and land filling of waste electrical and electronic equipment.
- Reduction of the depletion of scarce resources as an increasing amount of waste electrical and electronic equipment is being recycled.
- Reduction of the environmental impact and the depletion of scarce resources because ICT products will be developed and manufactured with a higher focus on end-of-life and recycling aspects.

The fulfilment of these predictions is of course based on the assumption that the intentions in the WEEE directive actually are implemented in all EU countries. There will always be attempts to reduce the cost of proper waste treatment e.g. to define the waste as “second hand goods” and export it to countries outside the EU (Gabel 2005). However, as much waste electrical and electronic equipment is being handled through reseller chains, who might put their reputation at stake if they were associated with irregular export, it is expected that most electronic waste will be treated according to the national regulations derived from the WEEE directive.

Another concern might be whether this directive (WEEE directive 2003) would imply any improvements based on a better design (seen from an environmental point of view). The article 7 requires that e.g. for IT and telecommunications equipment the rate of *“component, material and substance reuse and recycling shall be increased to a minimum of 65 % by an average weight per appliance”*. Though it is not clear from directive how the implementation of the article 7 should be supervised, it is expected to cause some improvement in many ICT-products and other products. At least some producers have been inspired by a close dialogue with an electronic waste recycling company in order to integrate the knowledge of the recycler in future product design, and thus decrease the time for disassembly and increase the rate of recycling and by that also reduce the cost for end-of-life treatment (Busch 2003).

The regulation will not directly foster the producers to develop products hazardous substances. This is handled in the RoHS directive (Con. Grau MST 2005).

3.3.2.2 Directive on the Restriction of the use of certain Hazardous Substances in electrical and electrical equipment – RoHS

The RoHS directive introduces ban on the use of lead, mercury, cadmium, hexavalent chromium, beryllium and on certain brominated flame retardants

(PBB & PBDE). The directive had to be implemented in national legislation by August 2004 (Ecodesign 2005).

In Denmark the statutory order LBK Nr. 1008 from 12/10/2004 is the legal implementation of the directive and is banning import and sale of the mentioned substances by 1 July 2006. ICT products are encompassed in the statutory order as well as a great part of possible embedded ICT applications in e.g. domestic appliances, electrical and electronic tools. Supervisory control is located at the Danish Environmental Protection Agency (LBK Nr.21). The directive will result in a softening of the existing Danish legislation by permitting higher limit values and including some exceptions on lead, aluminium, copper alloys and regarding mercury in different fluorescent tubes, which the Danish legislation do not encompass today (LBK Nr. 21), (LBK Nr. 1012), (LBK Nr. 1199) and (LBK Nr. 627). Through the chemical inspection measures will be performed to control compliance. This will probably be done by checking of rumours and by campaigns assessing different products through e.g. chemical analysis. These measures will probably be initiated in 2007 giving the business a change to implement the new regulation (Con. Heron MST 2005).

The Danish EPA has participated in different meetings, where business has discussed the impact of the directive and how it should be understood. At these meetings EPA has urged the business to build up co-operation and distribution mechanisms of experiences and knowledge. There is no overview of the scope of such initiatives but experience groups are formed. Furthermore B&O and Grundfos have participated in a project looking at producing lead-free (Con. Heron MST 2005).

3.3.2.3 The framework directive 2005/32/EC for setting up eco-design requirements for energy-using products – EuP

The directive does not introduce directly binding requirements for specific products, but does define conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics (such as energy consumption) and allows them to be improved quickly and efficiently (Ecodesign 2005).
After adoption of the Directive by the Council and the European Parliament, the Commission, assisted by a Committee, will be able to implement measures on specific products and environmental aspects (such as energy consumption, waste generation, water consumption, extension of lifetime) after impact assessment and broad consultation of interested parties (Ecodesign 2005).
The directive aims at creating a legislative framework for addressing eco-design requirements with the aim of:

- ensuring the free movement of energy-using products within the EU,
- improving the overall environmental performance of these products and thereby protect the environment,
- contributing to the security of energy supply and enhance the competitiveness of the EU economy,
- preserving the interests of both industry and consumers.

All energy driven devices are covered by the directive except means of transportation. Expected product categories that most likely will be regulated are domestic appliance, office equipment and consumer electronics.

Computers and televisions are predicted to be the first products to be regulated via EuP (Con. Traberg MST 2005).

The choice of products to regulate will probably be done by looking at environmental impact, the possible environmental improvement potentials and the volume of the product pool. A voluntary effort will be preferable (Con. Traberg MST 2005). It is likely that only those using electricity, solid, liquid and gaseous fuels will be the subject of implementing measures. The framework Directive defines the criteria for selecting products that can be covered by implementing measures (Ecodesign guide). The regulation can be standards for energy consumption, water consumption, noise, chemicals and recycling of products (Con. Traberg MST 2005).

If a product is regulated two different legal instruments can be used: limit values and “minor life cycle assessments”. For energy and noise it is supposed that limit values will be used. The “minor life cycle assessments” are supposed to contain an action plan where the producers has to make an assessment on specific substances, which the Commission define as important regarding the particular product (Con. Traberg MST 2005).
EuP will not overrule other directives as RoHS, and WEEE. National regulation will probably be overruled but the Danish EPA expects that the environmental gains through the directive will overcome the losses from degradation of some Danish regulation (Con. Traberg MST 2005).

In Denmark the negotiation with the EU Commission is placed at the “Energirådet” (Council of Energy) but as the directive will include possible regulation on energy consumption, water consumption, noise, chemicals and recycling, the implementation of the directive and the implementing measures will be a joint process between the Danish EPA and the Danish Energy Agency (Con. Traberg MST 2005).

3.3.3 Presentation of the areas of application for detailed analysis

Based on the project desk research, especially building upon the studies of Ryan (2004) and Berkhout & Hertin (2001), the interviews carried out in the project, and the project workshops we have selected five overall areas of application for ICT for further analysis, as mentioned earlier in the chapter. These areas cover fields, where the use and application of ICT has been highlighted as a possible strategy for achieving environmental improvements or present new or radically changing environmental risks. The five areas of ICT application are:

- Improving environmental knowledge
- Design of products and processes
- Process regulation and control
- Intelligent products and applications
- Transport, logistics and mobility

The application of ICT in improving environmental knowledge includes the use of sensors for collection of information about emissions to the environment or measuring the state of the environment, the use of ICT for comprehensive data processing and modelling, and the exchange of data and information related to environmental aspects among different actors within or between different societal arenas. This exchange could involve the public arena, NGO’s, environmental professionals, companies etc.

The use of ICT in the **design of products and processes** includes the use of tools like Computer Aided Design (CAD) in the design of physical products and Computer Aided Processing Engineering in the design of chemical products and processes in order to optimise different properties and aspects related to the life cycle of the products and processes.

The use of ICT in **process regulation and control** includes basically the use of ICT in the overall monitoring and control of industrial processes, energy systems, building management, and infrastructure systems in society. The possibility of online measurements of process parameters and the continuous regulation of processes in order to monitor and control different aspects of these processes represent today one of the most obvious and distributed application areas for ICT, which is more or less taken for granted.

The use of ICT in **intelligent products and applications** is a widely discussed area of ICT applications. Under the heading of e.g. pervasive computing, ambient intelligence and ubiquitous computing the examples of future visions are manifold. It includes the use of for example sensors to collect information, handling of these information in the product and the possibility of giving feedback to the users of the product in order to optimise the use hereof.

Transport, logistics and mobility is an area that is highly energy intensive due to the large amounts of goods transported and the growing personal mobility based on easier access to transport systems. The use of ICT has been discussed as means for the reduction of environmental impact in different ways. The analyses includes the role of telework (including telecommuting, teleconferencing a.o.), E-business (including teleshopping and B2B (Business to Business)), and transport logistics (surveillance, optimisation etc.).

3.4 Improving Environmental Knowledge

(Ryan 2004, p. 84-89) points out that ICT have had and can have big importance for the knowledge base within the environmental field:

- New systems of sensors can monitor the environmental conditions. The development of smaller sensor placed in sensor-net is expected to give better possibilities in environmental data-collection
- Distributed computer capacity with the possibility of complete comprehensive data processing is important in the processing of big data sets
- Increased exchange of environmental data in different networks including researchers, citizens, authorities, organizations, companies and others and sometimes across these groups

3.4.1 New sensor systems

Sensors could become a significant part of an improved environmental knowledge base in the future, but further development of sensors themselves is necessary to fully utilise the possibilities of this technology. The development of sensors with better precision and new functionalities will be important in the field of gathering new and reliable information (Ryan 2004 p. 85). Another important aspect will be the price of the sensors. The sensors have to become cheaper before they become attractive to an extent, which implies significant applications (Intelligent workshop 2). Sensors can be used to monitor pressure, moisture, vibration, magnetic fields and much more (Ryan 2004 p. 2004)

The general development of the sensor technology is expected to result in cheaper and smaller sensors through a general need for data in society. The development will include a miniaturisation that could include the development of wireless sensor networks. The driving force at the moment is not environmental applications, which means that the development and the use of sensors for environmental purposes are small compared to other markets for sensors (Int. Lading 2004). The present possibilities of using sensors to gather different environmental data are not at all used due to a very limited environmental interest. The general development in the sensor technology will, however to some extent be beneficial to the collection of environmental data, if the sensors are improved with respect to spatial and spectral resolution, image analysis and pattern recognition (Ryan 2004 p. 86).

Danfoss Analyticals sees a lot of different possibilities in the sensor technology for environmental purposes, if the market should need it (Int. Paasch 2005) & (Intelligent workshop group 2) (see also example later in the chapter). The market for sensors developed directly for environmental use could expand in the future years, if governmental regulation creates a need for this. One possible driving force could be the need for the new EU-countries to comply with EU-legislation within the environmental area (Intelligent workshop group 2).

Sensors integrated into sensor networks can run a software operating system, handle communications through e.g. radio motes (tiny, self-contained, battery-powered computers with radio links) and thereby transfer data along the net. The mote net the sensors are connected to, is so intelligent that they can reconfigure if a sensor are lost or new sensors are added to the network. To save energy the sensors are sleeping most of the time and waking up periodically to measure and send the data when a change in the environment are occurring. In the future these devices might be able to run on energy from light, heat and even on vibration (Ryan 2004 p. 86). For environmental purposes the sensor networks could be used to gather information from open areas instead of closed limited locations. An example is the possibility to use the technology to monitor the condition of a groundwater resource connected to a groundwater pump. It is possible to make a sensor network with a lot of not especially good or accurate sensors, which gather data from a big area of the groundwater resource. The information from one of the sensor would over time not give any interesting results, but when connecting them in a system and look at the patterns in the results the data could become scientific interesting (Intelligent workshop group 2).

Especially in the USA a lot of firms have tried to develop the so called lab on a chip, meaning that normal laboratory facilities, which today might demand a 100 m^2 room, could be integrated into a small chip so the sampling, analysis and data processing could be done in few minutes at the location. The idea is to make the chip so cheap that they after use could be discarded. Many of these attempts have failed and a lot of the firms have gone bankrupt, but still some expectations are found in this area (Int. Lading 2004).

The environmental implications of the use of sensors depend on the way they are used. If they are used for measurements in the environment it will imply an environmental strategy focusing on cleaning-up and remediation. If the sensors are used inside plants and facilities, they could become part of more preventive environmental strategies (Intelligent workshop group 2).

Danfoss Analytical.
Danfoss Analytical is a leader in Online Analytical Meters for the Waste Water Industry through a micro technology. The technique is a special filter that can separate ions from wastewater and only allowing the ions that is wanted for measurement in the meters.

The company sees potentials in development of sensor networks. The possibilities lie in linking sensors in big environmental measurement systems providing more data to assess and react upon. It could be possible to measure e.g. different discharges of wastewater both in public and industrial installations. More accurate measurements of the outlet of oxygen, ammonium, phosphate and nitrate are possible. Other applications could be monitoring of drinking water reservoirs, which enable reaction before polluted water is pumped into the supply system.

The problem with technological solutions as sensors and other micro techniques is the high production price per unit, why mass production is the only way to reduce the costs. To day the price on sensors are approx. 10,000 Euro, but in order to be interesting in sensor networks used in greater open areas the price has to be around 1,500 Euro. Sensors used in networks linked with each other will not work if distributed randomly. It is necessary to know their exact position to use the data they provide. The sensors need energy from a radio or telecommunication module. Using static electricity will not work, but use of energy from temperature changes could theoretically be enough, but the application has not been developed yet.

EU is the most important market and especially the environmental regulation is important. Environmental assessment and monitoring in the Eastern part of Europe is not very developed but these countries have to do it in order to comply with EU regulation. There might have great export possibilities both in relation to the waste water industry but also in relation to new environmental monitoring and control if regulation demands new efforts.

Source: (Danfoss Analytical 2005 & Con. Paasch 2005)

3.4.2 Distributed computer capacity

The analysis of data, for example collected by the sensors, needs in some cases substantial computer capacity. This includes the possibility to make large scale modelling which is depending on available computer power and software. This could be done by using distributed computer systems, which are expected to provide more computing power than the largest and fastest single computers at a fraction of price. The allocation of unused computer power is the essential idea. The idea is that millions of PC users voluntary provide their unused computer power in a network to help analyse data and performing computer simulations, that are understood as socially or environmental important. Conservative estimations are that distributed computer systems could provide 10 billion megahertz with over 10 thousands terabytes of memory and storage. The development of related software is gone from an initial phase to make new analysis possible (Ryan 2004 p. 89).

3.4.3 Increased knowledge, awareness and action from environmental data

The exchange of environmental data can take place at different arenas – internally in companies or within NGO or research communities. The Internet can be used by these actors to share their information and interpretation of issues within the environmental field. Such collaborative networks have benefited the earth, atmospheric and environmental sciences and the ability to forecast environmental conditions and management of natural resources and enabling large international scientific researches (Ryan 2004 p. 85). The gathering and assessment of the environmental data could also be used in different education purposes both at school level and at higher levels as universities (Ryan 2004 p. 87). Also the NGO community has developed their way of exchanging information and making information available to the public. Ryan stresses that the connection between knowledge, awareness and action rapidly has become a focus for application and further development of ICT, as a way of empowering communities. An example is EnviroLink that unites hundreds of organisations and volunteers with millions of people in more than 150 countries (Ryan 2004 p. 89-90).

A way to integrate environmental criteria in decision-making in industry is to integrate environmental data into systems like Enterprise Resource Planning (ERP). ERP is defined as systems that integrate a series of business processes such as management, monitoring and analysis and is often based on ICT-systems comprising a number of these processes. These systems comprise e.g. physical flows and it is expected that systems with consideration of environmental issues can be developed. The physical flows are described as ”bills of materials”, material flows and receptors. Flows of materials can be characterized in different ways: Elements (i.e. Cd), chemical substances (i.e. SO2), materials (i.e. wood), and parts of products (i.e. motors and bolts).

The existing systems support only to a limited extent the demand of information that is needed for an environmental optimization, but it is expected that such integration is possible since both logistics, which is a typical area within ERP, and environmental assessment are based on physical flows. The framework of ERP has to be developed further in order to integrate the environmental aspects, since today the economic criteria is far the heaviest component in the ERP systems. This way of thinking has to be changed before a functional integration of environmental issues can be performed (Lambert et al 2000 p. 109).

As part of their environmental management some companies use Intranet as access to procedures etc. Experiences from several companies seem to show that these ICT-based networks alone can not secure the necessary integration of environmental issues into i.e. product- and process changes. The reason is that many non-environmentally educated employees do not have the necessary knowledge to use these procedures, checklists etc. developed by environmental specialists. At the same time environmental specialists have difficulties in converting their environmental knowledge to concrete proposals for application in relation to process and product changes. Experiences seem to show that more dialogue between environmental specialists and for example the process- and product developers give a better integration of environment issues into decision making than environmental assessments based entirely on the individual use of procedures from Intranet.

Athena Greenline – Energy and environmental management.
Athena A/S is a Danish IT company that offers various IT-business solutions for organisations and companies and has won an EU-outsourcing project. Athena is one of the oldest IT-consultancy firms in Denmark and has various competencies in the fields where they provide solutions including knowledge about environmental issues. One of their solutions is Athena Greenline, which is a web-based energy and environmental management system for public authorities developed in co-operation with Kolding municipality and used in more than 200 institutions. It is used to make decentralized environmental registrations, targets and follow ups on the performance. The system is new and has only been in operation since June 2004, why an assessment of the improvement in environmental performance can not be provided but the expectations are at least 5-10 % and the success margin is only 1 % for Kolding municipality. The project has reduced the number of man hours used for the administration of environmental issues and making green accounts. The vision with the system is to help the municipality to foster a change in behaviour in all of their institutions.
The future of Athena Greenline is promising and in the merging of the three municipalities - Vojens, Haderslev and Gram Athena Greenline is used as a pilot project in the merging phase. In this way the system is used as a tool in the difficult merging processes. In the future Athena A/S wants to make a similar system for businesses.

The system has various functions including report of electricity, water and heat consumption, energy and environmental reports, energy monitoring and budget, environmental impacts from emissions of CO_2, SO_2 and NO_X, registration of transport, knowledge sharing on energy and environmental issues, registration of green purchases and registration of waste. These specific environmental factors can be changed and developed as it fits the organisation buying it, and Athena can give advice in these issues as well. Athena Greenline can help showing possible energy saving measures if needed. The management system can contribute to savings through a more efficient administration and by pin pointing poor environmental performances. For convenience of the user the interface is the Internet, which enables a recognizable fast and easy installation in the different institutions of a municipality and allowing both decentralized and centralized administration and monitoring. An environmental or energy portal is easy to make and the only requirements are basic knowledge on e.g. Word. Through an energy portal other actors have easily access to relevant snapshots of the performances. Athena Greenline makes automatically diagrams, tables etc. and could be the base for green accounts. The system is based on open standards and hence communication with other system used is possible so that historical data can be united in Athena Greenline. Athene Greenline shows the different users their performance compared to both former performance and compared to budgets and objectives and is capable of communicating with the responsible person, who is reporting data. SMS and emails are used to remind the responsible persons about registration both before schedule and if registration is lacking or diverging surprisingly. Sources: (Athena Greenline 2005, Athena A/S 2005 & Athena 2005)

Table 3.4.
Environmental impact from improved environmental knowledge.

First order effects	Increased environmental impact from an increased and more dispersed amount of ICT equipment and infrastructure. The impact will be smaller, if national and international regulation implies a reduction of the energy and resource consumption and the wastes and emissions from the manufacturing, the use and the disposal of the equipment
Second order effects	Depends on the application of the improved environmental knowledge base: whether the knowledge leads to action and whether the action is based on prevention and reduction of the impact at the source or mainly applied within a remediation approach
Third order effects	Depends on whether the environmental knowledge base leads to competitive advantages for companies applying this kind of environmental management, for example through changed governmental regulation or more knowledgeable citizens, consumers and authorities

3.5 Design of products and processes

The ICT-sector has increased by 8 % a year in the period from 1990-1997 in the OECD countries, which is somewhat higher than the general growth (Henten 2001 p. 12). Out of the 8 billion microprocessors produced annually only two percent ends up in computers. The rest ends up in production machinery, home appliances, and white goods, toys, cars, and other transport systems, mobile phones and PDA's, audio and video equipment etc. Estimates are more than 10,000 telemetric devices per person by 2010 (Ryan 2004 p. 99). The design of products and processes in general, and not only the electronic parts, might be environmentally improved using ICT-based tools for design and optimisation of products and processes. The environmental potentials in the design process are reduction of waste and increased energy efficiency. Often resource efficiency has been a part of the effort, though it is not a general trend (Ryan 2004 p. 102) & (Intelligent work shop group 2).

3.5.1 CAD and environmental databases

Design software and simulation tools can generate products, which fit better to its intended use. It is also possible to integrate environmental design criteria in CAD. It is, however difficult to assess the impact of this form of software disconnected from changes in materials and production processes (Berkhout & Hertin 2001 p. 10). One of the potentials in the use of CAD is the possibility to simulate several alternatives and prototypes with fewer resources

compared to physical product modelling, whereby CAD could enable more optimizing phases in a specific product design (Int. Lenau 2005).
Today computer programmes can guide architects to evaluate and compare the design of buildings with respect to layout, location, materials, isolation, shading etc. Research and development aim at integrating environmental databases into design processes to make it easier to choose materials and technologies. An example is LCA databases that can rate materials for designers (Ryan 2004 p. 98) and (Berkhout & Hertin 2001 p. 10). However, several subjective choices are connected to the use of lifecycle assessments (boundaries of the analysed system, choice of alternatives for comparison etc.). This implies that claiming that a certain product is environmentally better than competing products, based on the use of these methods, might lead to controversies. Most of the ICT based technologies used to simulation and design could become environmental tools if the designer wishes to use them for environmental purposes. The problem is that the designers often are focusing on other issues, like functionality, weight, strength and economy. These concerns might lead to environmental improvements (through less consumption of materials, fewer damaged products etc., but might also lead to higher environmental impact (Int. Torben Lenau, 2005).

3.5.2 Topology optimization

Another way of optimizing design is topology optimization, where calculations of products and constructions assess how the shape of an object enables the least consumption of materials, while securing the necessary strength of the product or the construction (Int. Sigmund, 2005). An example of such environmental achievements is the aluminium can where the amount of aluminium has been reduced by 50 % compared with a can 30 years ago (Berkhout & Hertin 2001 p. 10). Changes in aircraft motors and airframe structures are expected to contribute to a reduction in the use of energy of 20 % in 2010 and 50 % in 2050 (Berkhout & Hertin 2001 p. 10) and the typical optimization potentials on old classical and throughout optimized products are about 30 % (Int. Bendsøe 2005). The automobile and aircraft industry have a success rate on respectively 15-20 % and 0.5 % in reduction of weight when using topology optimization on different parts of their products (Int. Bendsøe 2005).

Topology optimization does not at the present stage integrate environmental concerns directly. An integration of environment concerns requires development of the right criteria related to the environmental issues for the system to be optimized, like the reduction of the weight of parts of an airplane or a better aerodynamic shape of a car so they consume less energy during operation. The concept of topology optimization is as concept relative simple. The difficulties in the method lie in the definition of the right framework conditions for the partial differential equations, which are solved as part of the optimisation, because every new type of design problem needs a new definition of the framework conditions (Intelligent work shop group 2).

The future research challenges would be to use topology optimization for multi physics where e.g. pressure, temperature and structures interact with each others. It could be a water pump that generates heat and thereby wear mechanical parts of the pump. This implies that different schools of optimization have to be connected so that both raster representation and edges approaches are used. To day this link does not exist. Furthermore new and better optimization algorithms have to be developed. The problem is that to day companies, which develop these algorithms, do it for large scale usages based on general problems. To use the full extent of topology optimization potentials more specialised algorithms have to be developed. The commercial aspect is the key problem because big international software companies develop these algorithms and they look at the commercial perspectives of their products. In this way the development of software can be a bottleneck for the development and usage of topology optimization.

Another area that topology optimization could be used for is the enclosure of a process, e.g. catalysts or fuel cells, where the method could be used to secure e.g. the most optimized cooling of the system (Int. Bendsøe 2005), which implies cooperation with process researchers and developers as e.g. those working with computer aided process engineering presented below.

In Denmark topology optimization is driven by basic research and the Danish industry is only in a limited extend using it in practice. At the universities the research is at DTU and at Aalborg University. There are only a few companies in Danish industry, which use topology optimization. One of them is Grundfos, where own software was developed 10 years ago. Spin offs from these research environments have resulted in a new and promising Danish performance in fibre optics where topology optimization are used as a basic tools in new products, where the optical computer is the vision. The optical computer will theoretically have greater performance on marginal lower energy consumption (Int. Bendsøe 2005).

A further development within the design area is a combined web-based waste exchange in order to obtain increased recycling. This will demand modelling and product design focused on easy disassembly, like concepts as Design for Disassembly and Design for Recycling. A greater application of such exchange processes seems, however to demand more closed circuit of materials within many product areas than today (Ryan 2004 p. 64).

3.5.3 Computer Aided Process Engineering

Computer Aided Process Engineering as practiced at for example the Department of Chemical Engineering at the Technical University of Denmark is an example of integration of environmental parameters into an IT-based tool for design of products and processes. The key of the tool is the capability through simulation of chemical processes to design and optimize the processes by using partial differential equations for balances of energy and mass and for phenomena like heat transfer etc.

Energy integration at chemical plants can be used to increase the efficiency of the consumption of natural resources and limit pollutant emissions as distillation is far the most widespread solution for industrial separation processes. Distillation stands for around 3 % of the total energy consumption of the Western world so an increased efficient distillation process is very much desired and is possible to obtain through energy integration. Energy integration is basically the reuse of primary energy stream within e.g. a distillation column (Koggersbøl et al. 1996). The process automation could be based on energy and material balances including controllers for the levels in the reboilers, the condensers and accumulators tuned by rules ensuring closed loop time constants at 1 minute for a stable process (Koggersbøl et al. 1996 p. 854).

Another programme can be used for design of solvents through simulation (Computer Aided Molecular Design) fulfilling certain environmental and health related criteria by computer modelling. The tool has integrated energy and mass balances and the WAR-algorithm (WAste Reduction algorithm), developed by the US Environmental Protection Agency (EPA). The proposed solvents and compounds are assessed and ranked based on their environmental and health related properties (Int. Jørgensen 2004). Similar models have been used for modelling more energy efficient separation processes in industry financed by the Danish Ministry of Energy and initiated because of increasing energy costs. Some Danish companies are part of the network and co-operation partners of the centre, but the interest in these models and the possibilities for optimisation of environmental, energy and health aspects seems to be bigger among businesses in foreign countries, if assessed by the number of co-operation partners. The type of calculations involved in the optimisation depends on the increased access to computer based data processing capacity. Calculations done to day in a few minutes would have taken several days 5-10 years ago (Int. Jørgensen 2004). These tools can be linked to more overall strategies for rationalisation of production processes, such as LEAN and “LEAN-thinking” (Int. 2 2004), (Int. 3 2004) & (Ryan 2004 p. 103) where this understanding of manufacturing and business processes helps identifying bottlenecks or so called critical points. These critical points are seen as the best way of handling the optimization problem (Int. 2 2004). Environmental aspects are normally not directly included in LEAN optimisation. In case the optimisation focuses on reduction of wastes the optimisation *might* lead to reduction of resource consumption and reduced amount of waste.

The designers have to look at the optimization or design process as a whole with a lot of factors that might not be within their expertise in order to obtain an optimal design and planning. Participation of a number of professional groups in these processes requires bigger computers to handle all the specifications and the information at the same type of computers and thereby avoiding mistakes when transferring data from one type of computer software to another (Int. Jørgensen 2004). (Intelligent workshop group 2).

Table 3.5
Environmental impact from design and planning of products and processes.

First order effects	The environmental impact from the equipment for data processing is probably not increasing due to the increased data processing power per computer. The impact will be smaller, if national and international regulation implies a reduction of the energy and resource consumption from the manufacturing, the use and the disposal of the equipment
Second order effects	Depends on the focus of the optimisation. There is no guarantee for environmental improvements from these kinds of product and process optimisation. The focus of the optimisation is determined by governmental regulation, including resource costs, waste management costs etc.
Third order effects	Depends on whether environmental focused optimisation leads to competitive advantages for companies applying environmental management, for example through changed governmental regulation or more knowledgeable citizens, consumers and authorities

3.6 Process regulation and control

Higher resource efficiency can be obtained through a more effective use of materials, less re-manufacturing of low quality products, better logistics and better understanding of the material flows (Ryan 2004 p. 103), (Int. 2 2004) & (Int. Jørgensen 2004). Modern production systems can have thousands of individual microprocessors embedded in them, controlling valves, measuring temperatures, sensing the properties of fluids etc. Today up to 40% of the value of a new manufacturing process is accounted for by the control systems.

Precise control is essential for minimising emissions, and waste is an indicator of inefficient processes and process management. Resource productivity improvements of this type have been achieved consistently since computers were introduced into manufacturing over 30 years ago (Berkhout & Hertin 2001 p. 10). Also facility management in buildings regulating the temperatures, lighting etc. is a field of application for ICT-based process control and regulation.

The use of ICT systems in energy technologies has resulted in improvements in energy efficiency through control of lights, motors, boilers, air-conditioners and water heaters. All of this can be integrated into energy management control system (EMCS) which can be assessed and controlled by the Internet (Ryan 2004 p. 107) and (Intelligent work shop group 2). The development of wireless networks used in EMCS could become a driver in the further use of sensors. The technology exists and it is only up to businesses to use it in different applications. Research and development should ensure that different types of equipment can communicate. Development of standards is seen as one of the most important tools in securing an implementation of wireless solutions. When different standards are developed it could be fatal for smaller companies to choice the wrong standard (Intelligent workshop group 2). This is a challenge for the Danish market because it is characterised by a lot of small and medium sized companies, and the development of the standards is not happening in Denmark (Intelligent workshop group 2).

There are big differences in the type of production from sector to sector, but it seems possible, at least within several chemical and biotechnological areas, in the future to obtain a reduction of the resource consumption and the amount of wastes and emissions by going from quality control of final products to online quality control through regulation of the production processes. Traditionally GMP (Good Manufacturing Practice) rules and guidelines, from for example the US FDA (Food & Drug Administration), has limited process development and process optimization because of a high bureaucracy and paper work in the approval and re-approval processes. A future concept in the pharmaceutical industry is Process Analytical Technology (PAT), which is the result of a new regulation strategy from FDA (U.S Department of Health and Human Services 2004) & (Int. 2 2004). The purpose of the new strategy is not environmental achievements, but the release of personal resources for the development of more new products by reducing the control of final products and the amount of waste and re-manufacturing by introducing a more flexible on-line process regulation (Int. 2 2004). The base is the development of ICT-based tools, which makes it possible to make more complex calculations. This could also be used to regulate processes closer to the actual demands (Intelligent workshop group 2).

The background for the development of these possibilities in process regulation and also the previous mentioned possibilities in computer aided design are process and production design based on mathematical models, an increased chemical understanding of the processes and process regulation based on the development in online measuring methods and online systems of regulation. The development is directly based on the development of ICT where the data processing power is and has been the limiting factor. Other ICT technologies, important for the online regulation, are sensors coupled to communication network and computer assisted control. Such systems are needed to gather data and transform it to information so that the regulation can be performed (Int. Jørgensen 2004) and (Int. 2 2004).

3.6.1 Process automation

Process automation includes various solutions but plant stability, controllability, operability and safety are the main issues, when discussing plant processes and intelligent control and regulation through process automation of nonlinear processes (Koggersbøl et al. 1996; Szederkényi et al 2002). These factors have to be in order when designing process control and plants. Other keywords are traceability, audit trail, product quality and batches, and ICT solutions are an integrated and essential part of process automation.

Introducing such stringent regulations in industrial plants can be done by artificial neural network (ANN) to secure product consistency, reduced operational costs, and improved safety through a structured and well designed processes control and plant management (Cox et al. 2001 p. 302). ANN have the ability to learn from past process data and thereby model the complex non-linearities of a process and are capable of accommodating multi-input multi-output (MIMO) systems. ANN is not relying on an understanding of the processes they control, but produces a model based solely on previous behaviour of inputs and outputs from the plant. This can be understood as feed-forward control strategies (Cox et al. 2001 p. 299 and 302). ANN is hereby capable of e.g. introducing the right doze of chemicals to a process based on the characteristics of the input compared to a manual dosage by a chemist (Cox et al. 2001 p. 298-300). Furthermore, auto-associative neural networks are capable of identifying sensor failure and aid signal reconstruction has been developed and tested both in pilot plants and at larger products plants (Cox et al. 2001 p. 302).

Another approach for process automation is Manufacturing Executing Systems (MES) where ERP and other management programmes are connected through software with production and process controls. Traceability and transparency will be issues in the future for process automation solutions. Traceability provides knowledge to managers and sales departments about the current status of a specific product or batch, which is an area that is highly developed in big international companies and will in a few years be a demand from Danish companies as well (con. Jacobsen 2005; con. Nilsson 2005). Some of these software programmes include the possibility of measurements on environmental factors. These factors can focus on the processes before emissions are emitted to air or water. The factors have to be defined by the user and are optional. There is no knowledge available about how much this feature is used (con. Nilsson 2005).
Driving forces in Danish industry in process automation is regulation from EU and USA, mostly from GMP and FDA (Food and Drug Administration).

The area is highly regulated especially in the pharmaceutical and food industry (con. Jacobsen 2005; con. Nilsson 2005). Environmental issues is very seldom a issue when companies implement new ICT solution for increased process automation though a few big international companies such as MacDonalds demand that environmental issues are assessed by their suppliers (con. Nilsson 2005). Process automation in Denmark is based upon knowledge developed in other parts of the world and especially software solutions are bought from international software companies (con. Jacobsen 2005). On the other side Scandinavian companies have a sound

understanding of ICT and the possibilities for increasing effectiveness so they are relatively fast to incorporate new measures (con. Nilsson 2005)
E.g. a consultancy company as Birch and Krogboe with a formulated focus on environment provides analyses of needs (technical, strategic, legislation), specifications of requirements and make the tender materials for their customers and have furthermore cooperation with Danish entrepreneurs like Picca Automation and CIRKOM and has contacts with universities environments where e.g. business PhD's are performed (con. Jacobsen 2005).

The intelligent pump.
To day the intelligence in the electronic regulated pump is used for electronic management of the pump engine it self and hydraulic features. The intelligence is supporting a sufficient use with a decreased use of energy.

The management of pumps makes multi-pumps possible with monitoring of the systems operations and integrated alerts if any problems occur. Centralised management is possible through communication technologies so big organisations, e.g. municipalities can control all of their water treatment plants from a central command centre. The management of a system of pumps optimizes the performance of the system, lifetime and the sturdiness compared to single pumps.

It is possible through sensors to increase the functionality of the pump by integration of measurements of temperature, pressure, flow etc. In the future it might be possible to make the intelligent pump, the communicating pump, which makes measurements of the environment around the pump while pumping the liquids. The use of sensors in pumps makes it possible to gather data that could be communicated to a central command centre where data analysis could be done and used as base for changing the operation of the pump.
The vision of the intelligent pump is that it should be adaptive, one-fits all and self-optimizing.

To make the vision reality, knowledge of the rest of the installation and plant and the sensors are necessary and the advantages are suggested to be a simple installation, increased comfort and decreased use of energy.
Critical factors for the visions of the future pump solutions are the price, the size, the energy consumption and the ability to communicate with other control equipment (Intelligent workshop group2).

Management of energy in households.
Energy management in the future home will include the possibility to switch of and cut of lights and plugs, so that the stand by energy consumption is reduced. Curtains and Venetian blinds can be controlled by through remote controls or pushbuttons. Another property in the intelligent system is that one can control the energy through the Internet hence one does not have to be at the location. A key card will, when entering the home, turn on the desired and pre-programmed devices and services. Sensors will register the presence of persons and turn on lights where needed. Ventilation can also be managed intelligent so the ventilation will perform after demand e.g. after a bath.

The intelligent system will also provide easy available data about the energy consumption and inform about broken windows or insulation that is failing. The consumption data can automatically be sent to the supply company. Finally it can be connected to security systems as burglar, fire and humidity alarms if desired.
These ideas exist in single installations and equipment can connect them into one system.
Sources: (Devi 2005, Balslev A/S 2005 & Dans Bredbånd 2005)

Table 3.6.
Environmental impact from ICT-based process regulation and control.

First order effects	Increased environmental impact from an increased and more dispersed amount of ICT equipment and infrastructure. The impact will be smaller, if national and international regulation implies a reduction of the energy and resource consumption from the manufacturing, the use and the disposal of the equipment
Second order effects	Depends on the focus of the regulation and control. There is no guarantee for environmental improvements from these kinds of process regulation and control. The focus of the optimisation is determined by governmental regulation, resource costs, customer demands etc.
Third order effects	Depends on whether the environmentally oriented process regulation and control leads to competitive advantages for companies applying this kind of environmental management, for example through governmental regulation of emissions, energy costs etc.

3.7 Intelligent products and applications

This section focuses on so-called "intelligent products" illustrated by an increased functionality and reduced environmental impact through the application of ICT in products and hence more intelligent products. An often applied concept regarding intelligent products is ”pervasive computing”. ”Pervasive computing” is characterized by being embedded, wearable and persistent – and hence capable of communicating with the user and other objects, where knowledge can be saved and information can be passed on. In a foresight on pervasive computing organised by the Danish Ministry of Science, Technology and Innovation the technology is presented as having big developing potentials and limitations in possible applications are nearly non-existing (Ministeriet for Videnskab, Teknologi og Udvikling 2003).

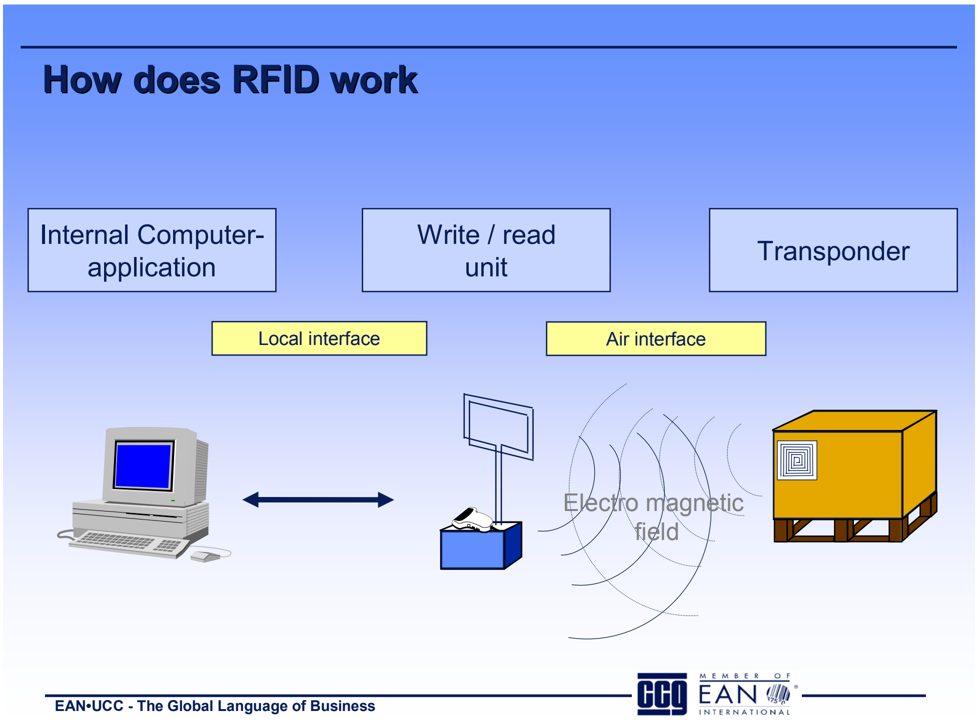
As an example, sensors and control systems in households can secure that different services are delivered effectively and only when needed. Even though this development is not driven by a wish for a better environment, but often a wish for economical savings and increased capacity utilisation and functionality the development has increased the resource efficiency. (Ryan 2004) argues (although without documentation) that the improvements have been significant and there are possibilities for further improvements. The potentials are described as follows (Ryan 2004 p. 103-106):

- Intelligent functions and operation: sensors integrated in products contribute to automatic optimization of the function of the product resulting in a more resource efficient operation.
- Operational feedback to the user about possible choices which can result in a higher resource efficient operation of products in cases where the user behaviour influences the uses of resources.
- Digital product information and diagnoses (batch wise or on-line) related to maintenance, reuse of components etc.
- Product integrated in a digital network pass on information to user or service provider (e.g. the possibilities of use of electricity in low load cycles).
- Digital upgradeable products so products do not have to be discarded when new functionalities become available at the market.
- Digital product-"DNA": Information saved in the product (maybe through use of RFID-tags) about material volume, producer/batch information, instructions for disassembly in the reuse phase etc.

- Substitution of hardware with software: from CD to digital music, from photos to digital photos etc.
- Digital improved product/services systems, i.e. systems for services like car sharing.

An example of applying sensors for a so-called intelligent function could be to integrate them in different constructions and devices with the purpose of giving information if the constructions or products are starting to fail. This could enable reduced resources for maintenance, since maintenance would be done on demand and not after a planned schedule (Intelligent workshop group 2).

Radio Frequency Identification – RFID.
Radio frequency technology enables electronic contact-free identification (of individual items or transport batches), control and tracking of one or a whole range of items in the value chain and in every company in the chain. Similar to barcode technology, RFID also reads data carriers – but in stead of using optical wavelengths, RFID uses radio frequencies. Alternating electromagnetic fields are used to carry data. RFID can do this independently of the position and place these objects are kept. No line-of-sight is required between the reader and the information carrier (TAG). (ECRNET 1 2005)



(ECRNET 2 2005)

The first order impacts from an increased use of pervasive computing components, devices and infrastructure are increased material and energy consumption, waste and emissions of pollutants. Its is likely that rare materials as gold get depleted and hazardous materials as heavy metals and halogenated flame retardants increasingly will be released to the environment because of the characteristics of pervasive computing products and components (Erdmann & Behrendt 2004 p.566-567):

- Throw away products.
- Miniaturized products that are difficult to dismantle.
- Too small content of valuable material for recycling.
- Quality problems in the recycling processes.

- Reduction of useful life time by embedding of ICT in other products (the product has to be updated).
- Increased energy consumption by always being turned on, increased number of energy consuming objects because of the embedded ICT and need for increased networking.

An environmental effect of further development in pervasive computing can be an increased amount of products that have to be treated as electronic waste with the difficulties related to electronic waste in reuse and disposal mentioned above. This picture could be challenged by a change from silicon based chips to i.e. polymer-based chips and the future possibilities could include printing electric circuit based on polymer on local "inkjet printers" or polymer based electric circuits mass-produced for a certain purpose. A conductor, a semiconductor, an isolator and solvents are the ingredients for a polymer-based chip. It is not sure that the polymer based circuits will be totally free of metals. The solvents are not better or worse than those used to day in other applications (Intelligent workshop group 2). Going from wire-based to wireless transmission will have some benefits because the materials for cables are not needed. On the other hand, this change towards wireless communication implies risks of safety and security problems and electric smog. Regarding the security problems development is in progress to ensure that the security will be sufficient (Intelligent workshop group 2).

The problems with electric smog are uncertain and not well studied, though it is suspected to have some effect on the biologic organism. Some studies are made upon the impacts of non-ionizing radiation, which concludes that some biological effects are proven, but no adverse health effects are proven. An example is thermal impacts and changes in the calcium transport of the nerve system, but no damage effects are proven (Erdmann & Behrendt 2004 p.568). The effect on the human organism or other organism is somewhat uncertain, but some effect could be assumed and are determined by some factors as number of sources, emission power, frequency characteristics, time characteristics and distance to body (Erdmann & Behrendt 2004 p.568). Sensors function by a low effect compared to the effects of mobile phones, radios or other devices function. Hence it could be considered that electro smog from operating sensors could be minimal compared to other electrical equipment that surround us (Intelligent work shop group 2).

Health impact of Electromagnetic radiation.

Daily we are exposed to increased amount of electromagnetic radiation due to the increased use of electric equipments, mobile phones, surveillance equipments, wireless systems, high voltage power lines, mobile phone masts, dishes, radio transmitter etc. The knowledge about the impact on humans is sparse and research is carried out all over the world. Preliminary results show that the radiation has an effect on the human body and changes can occur in different control systems, which might have a short time effect on brain and nerve functions and in the long run it might result in severe illnesses as cancer (Kwee p.1). The results from research on electromagnetic radiation are very ambiguous and depend on the approach to the area. There is no direct documented relation between e.g. cancer and radiation from mobile phones as such, but when looking at radiation from the pool of electronic equipment that surrounds humans and the total exposure of radiation to humans in long perspective conclusions might differ (Teknologirådet 2004). Knowledge about this continuous and repeated radiation is sparse (Kwee p. 4).

There are great differences in the radiation from low-frequency and high frequency radiation. Low-frequency radiation comes from electronic equipments and high voltage power lines while the high-frequency radiation comes from radar, radio, TV, micro wave ovens, mobile phones and wireless systems. In mobile phones and wireless phones the radiation is also pulsed with a frequency, which gives the different patterns that the phone companies use when sending signals from masts to the phones. These pulses are expected to be those with the highest health impacts, because they are in the same area as human brain and organs waves and several thousand times more powerful (Kwee p. 1-2). Ionization radiation is e.g. X-ray and gamma radiation and is proven to harm cells and destroy DNA and is not interesting regarding electronic equipment. Neither the low or the high frequency radiation have enough energy to directly change cells, but they can give so much heat, which has to be removed from the area it effects, otherwise changes might occur. Areas of concern which researchers have pointed out regarding high-frequency radiation include:

- Changes in genetic material: DNA and chromosomes that might be an indicator of cancer and Alzheimer.
- Appearance of brain cancer among mobile phone users is highest among 20-29 year old in a ten year period.
- Brain scanning showing that 30 minutes radiation results in changes in blood circulation in the inner brain.
- Brain scanning showing that 10 minutes radiation results in leakiness in the blood brain barrier that protects the brain.
- Biological changes on genes, immune system, response to stress and cell growth.

(Kwee p.2)

In epidemiological research on the effect of high-frequency radiation brain cancer, breast cancer and other leukaemia at children, bad well-being and allergy to electricity are found. In biological research laboratory experiences on irradiated cells or organs from humans and animals and experiences on irradiated animals and on humans changes in cells, organs, immune system, growth, fertility, DNA, chromosome, brain function, hormone and heart function and a increased response on stress was seen (Kwee p.3). These results have not been obtained by other researchers and in general the researchers do not see a documented relation between radiation and health problems. More research has to be carried out before the relation can be excluded or documented, especially the effect in a long term perspective (Teknologirådet 2004) & (Grandjean). Other areas that have to be examined are neural and cognitive effects (Teknologirådet 2004 p.2).

Children is a risk group because their brain is not fully developed before 16 years of age and children most important brain waves have the same pulses as mobile phones use. The fact that children grow faster and their immune system is not fully developed could be important to look at in a health care perspective. Children reactions are influenced more powerfully by mobile phone radiations, and Swedish research shows that the an increased amount of cancer cases are seen within the group that started to use mobile phones at 10-20 years of age (Kwee p. 2).

The future will bring more use of mobile phones and with the new 3G technology the possible problems with pulses will increase. The 3G technology has a marked pulse radiation (Kwee) & (Teknologirådet 2004 p. 3). The future will also probably also bring a discussion about changing the limit values based on the research results and the precautionary principle. To day the limit values are defined by the ICNRIP – an international committee and it is defined in two ways: Density and the concrete specific absorptions rate (SAR) (Johansen p.3). The density shall be less than 10 W/m^2 and the SAR value shall be under 2 W/kg (Andersen 2004). Some of the health risks, which are possible, are supposed to come at lower radiation than the limit values but other researchers say that these research results are not well documented (Teknologirådet 2004). They argue that more research is needed to conclude if e.g. the use of mobile phones is safe or not (Johansen p.5)

In Denmark the National Board of Health has formed a research panel that shall guide them in the future about the mobile phone health risks. The panel has representatives from various subject areas such as epidemiology, geomedicine, statistic, laboratory experiments and mobile technology (Teknologirådet 2004 p. 4). The Danish government has initiated research on electromagnetic radiation in a research programme on mobile radiation at a total of 4 million Euro in 2004-2005. The research programme is supposed to identify health care risks including long time effects, impacts on young and children, needed knowledge in the area and which international competences that can be used (Elvekjær 2004 p.1)

Regarding the extreme low frequency radiation (ELF) from e.g. electrical devices and high voltage power lines there is limited evidence on humans about the carcinogenicity in relation to childhood leukaemia and inadequate evidence in humans for the carcinogenicity in relation to all other cancers as well as for the carcinogenicity of static electric or magnetic fields. Overall ELF might be carcinogenic to humans and static electric and magnetic fields but ELF fields are not classifiable as carcinogenic to humans (IARC 2002). People with epilepsy, a family history of seizure, or those using tricyclic anti-depressants, neuroleptic agents and other drug lowering seizure threshold are likely more sensitive to very low frequency fields (VLF) such as monitors (NRPB p. 67 2004)

Another problem related to electro smog could become safety problems related to electrical interference between different systems due to the increasing number of wireless systems. An example is the allocation of radio frequency 24 gigahertz to anti-collision radar in automobiles made by the EU. The thousands of such automobile radars will interference with the moisture measurements essential for the mathematical models used by weather forecasters. The consequence will be less reliable weather forecasts in the future (Ingeniøren 2005 p.6).

The second order effects of pervasive computing might include a shift from product ownership towards service, where users share products through use services. This could imply that the pool of products will decrease in the future, but it is a very uncertain conclusion (Erdmann & Behrendt 2004 p. 566-567). Another element in service-based business could be that companies selling services instead of products will have more control of the devices and equipment used in the services, and it is more likely that they will have economic incentives in securing that the operation are optimized. An example could be that a company providing heat to houses also controlled the thermostats so that they secured that an agreed temperature were provided. In this way it is not the heat that is sold but the services of comfort (Ryan 2004 p. 106-107).

3.7.1 Polymer chips and sensors as enabling technology

Polymer chips and sensors are often given a role as an enabling technology in relation to pervasive computing. The research on polymer based actuators is a relatively young discipline and dates back to early work by Kuhn and Katchalsky in the 1950'ies. Progress was obtained from 1980 and today around twenty groups in Japan, Europe, US and Australia are working in the field. In Denmark research within this field is especially done at the Danish Polymer centre based at Risø, DTU and Danfoss and has been going on since 1996 (Sommer-Larsen).

A specific group of polymers, the conjugated polymers, can be used either as semiconductors or when powerfully doped as real electric conductors. Slower than silicon based chips, but cheaper and more flexible, organic, or carbon-based electronics may promise low-cost, large-area devices such as ultra flat panel displays (Computerbits 2003). New materials of conjugated polymers have proven to be stable and easy to manufacture so that they are interesting to use as semiconductors. Those which can be used in LED's and in area effect transistors (FET's) as a thin film and with the properties of polymers. As polymers they are light, flexible and their properties can be manipulated to special needs. Emerging technologies like polymer actuators, polymer LED's (light emitting diodes), and polymer solar cells will be possible in the future (Danish Polymer Centre 2005). Anticipated applications are: displays, RFID-tags for product targeting, inventory control and electronic smart cards for personal security. It could control new products as roll up TV screens, electronic papers handled as conventional paper and RFID (theft protection or bar code identification in stores). Furthermore they might have a justification regarding development of sensors and sensor networks (Computerbits 2003) & (Intelligent Workshop group b).

Polymer based transistors will be significant cheaper than traditional silicon based. A site for manufacturing of silicon chips would cost approximately three billion dollars compared to a large-area integrated circuits composed of organic or plastic transistors can be produced at low cost using simple patterning techniques in ambient environments. Manufacturing of plastic transistor circuits using an inkjet-type printer is a low-waste process and offers a simple direct-write capability and high manufacturing productivity. The price of a manufacturing site will approximately cost thirty million dollars (Computerbits 2003).

The innovation of a polymer transistor is the main barrier for the development of integrated circuits and chips. The main advantages of the polymer chips will be the price and not the performance, so they will not substitute the silicon based chips in e.g. Pentium processors. New markets will be possible e.g. the “use and dispose” electronics (Nielsen 2005). Demands for polymer actuators are e.g. low price materials, linear acting, smooth movements allowing integrated feedback and control (Sommer-Larsen).

The technology is not new but the problem with low maximum speed of the polymer semi-conductor has limited the commercial interest. New research in the polymer crystalline construction influences its speed limitations. At Risø and HASYLAB in Hamburg X-rays measures for the analysis of the construction of the polymers have been developed so that a more focused research can be carried out for the development of fast polymer semiconductors (Nielsen 2005).

Application has been tested in research on alternative actuators used in robot. Actuators based on polymer materials and dielectric elastomers can be constructed on both micro and macro scales and compared to conventional actuators such as electric motors, hydraulics, pneumatics and solenoids they have promising performances. They can fulfil the requirements of driving e.g. a dextrous robotic gripper. Another polymer based solution is actuators based on polymer gels, but its performance does not fulfil the same requirements for speed etc. but it could be used for medical applications (Sommer-Larsen). Other problems with polymer chips are their unstability with respect to temperature, but solutions using polythiophene are stable and resistant at room temperature. Companies as Lucent, IBM etc. unsuccessfully have tried to stabile polymer based solutions for many years (Computerbits 2003).

3.7.2 Cases

In the following two cases on intelligent products are presented. The development of vacuum cleaners shows that intelligent products might not be the most efficient strategy for reduction of energy consumption. The case about the intelligent automobile shows the complexity in changes of the environmental impact from the use of a product and shows that the introduction of an energy efficient component or product does not ensure reduced energy consumption. The market development for the products depends on the complex interaction between suppliers, users and the general societal development. An example that shows that political initiatives may have a direct environmental effect, if they are implemented in a way that involves several stakeholders, is the Danish energy label on refrigerators etc., which have moved the sale from very energy intensive to less energy intensive products (Intelligent workshop group 2).

The development of vacuum cleaners in Denmark.
The development of vacuum cleaners in Denmark can serve as an example of the potential improvements from the development of intelligent equipment. The vision is to develop new user operated intelligent vacuum cleaners that ensure cleaning after demand. To day the manufacturers of vacuum cleaners focus their development and their marketing mainly on as high an engine effect as possible, even though the engine effect has no direct relation to the cleaning efficiency. Furthermore the high effect is an environmental problem because of the higher energy consumption in the use phase.

One manufacturers’ vision for the future vacuum cleaners is cleaning after demand, based on a differentiated use of engine power depending on surface and degree of dirt. The engine effect needed to clean different surfaces is very varied, e.g. a very low engine power is needed to clean curtains compared to carpets. Using sensors to determine the type of surface and the degree of dirt could reduce the energy used for vacuum cleaning. When engine power is reduced the noise will also decrease. Another aspect would be the possibility to monitor the filters (maintenance), indication of a full dust bag and feed back about the cleaning degree to the user, enabling faster and sufficient cleaning. To make the vision a reality, sensors used for vacuum, airflow and optical sensing have to be developed and available at low cost.

The potential energy savings are predicted to be (at a 1200 W household vacuum cleaner):
Carpet cleaning (sufficient cleaning, shorter time) 20 %
Hard floor cleaning (power reduction, shorter time) 35 %
Light fabric (curtains and similar) 60 %
Running idle: 100 %
Estimated total savings: 30 %

The new EU energy label for vacuum cleaners is expected to contain a lot more parameters regarding energy consumption than only engine effect. Issues like functionality and environmental aspects are expected to be integrated, which could be a way to support the development of the intelligent vacuum cleaners. The consumers will have a more transparent market and have the possibility to choose from a wider perspective than only engine power and price. It should though be said that environment is not a parameter which is considered in the present product development (Intelligent workshop group 2). Compared to the energy reduction, which can be achieved from an intelligent vacuum cleaner, a reduction of the engine effect to maybe 600 Watt through an optimisation of the drawing effect, might give bigger energy savings The saving becomes even bigger engine when comparing with the effect of new vacuum cleaners of 1800 Watt and 2000 Watt and show that the savings which may obtained from intelligent products are not necessarily as big as those which can be obtained from a more fundamental change in the product concept.

The intelligent automobile.
An example of the complex relationships between the ICT-development and the environment can be illustrated by the later year's development in design and use of automobiles. Despite of the development of more energy efficient automobile engines the use of energy for transport is constantly increasing. The automobile has been changed dramatically through the development of its internal information and control systems. Today up to 30 % of the manufacturing costs to automobiles can be for electronically parts. The reductions of the environmental effect from automobiles are based on efficiency improvements through sensors, electro-mechanical devices, actuators and operations systems. Environmental development opportunities related to information about the automobiles geographic position, atmospheric conditions, traffic conditions, distances, speed-controls etc. are seen (Ryan 2004 p. 100).

Hybrid cars with fuel engines and electrical engines or batteries build on complicated IT-based control of the combination of the different engines (Berkhout & Hertin 2001 p. 11). The control gives significant savings in resources and reduction of the use of fossil energy on approximately 70 %. It is possible to develop automobiles with a better environmental efficiency, but because of the approach to the automobile from the customers, automobile producers etc. the market penetration of these types of cars are modest. Focus is instead on automobiles with increased functionalities, which often oppose the environmental potentials (ex. the use of energy for air condition and increased weight due to different forms of new equipment). Smaller automobiles with lower fuel consumption are to some extent purchased by families as the second automobile, which often will result in increased use of energy. There is an interaction between the possibilities that a product as an automobile can offer and the consumers' perception of their demand for transport. I.e. the availability of a car often implies an increased need for transport in response to the increased mobility. The need for transport can also increase if a family settles far away from their respective workplaces in response to increased house prices in areas near workplaces or because companies centralize their facilities by closing down a number of sites and concentrating activities at fewer sites. This shows how the development and application of products are shaped in interaction with the societal development.

Table 3.7.
Environmental impact from intelligent products and applications.

First order effects	Intelligent products may imply an increased environmental impact from an increased and more dispersed amount of ICT equipment and infrastructure. The impact will be smaller, if national and international regulation implies a reduction of the energy and resource consumption and use of hazardous chemicals and materials during the manufacturing, the use and the disposal of the equipment
Second order effects	Depends on whether and how the environmental aspects are part of the focus in the development of intelligent products and whether new and maybe more efficient products substitute less efficient products or the fleet or the stock of products among consumers and other groups of users increase. The focus of the development of intelligent products and applications is determined by governmental regulation, resource costs, customer demands etc.

Third order effects	Depends on whether the intelligent products and applications focusing on reduced resource consumption etc. give competitive advantages for the companies, for example through governmental regulation of emissions, energy costs etc. Depends also on whether reduced resource consumption from more intelligent products induces a rebound effect, where more products are bought because of savings from reduced resource costs.

3.8 Transport, logistics and mobility

The transport sector is both one of the most energy consuming sectors, and also one of the sectors having the largest potential for reduction in negative environmental impacts through use of ICT technologies.

In particular in the US, ICT has been seen as a way to change a clearly unsustainable trend in the transportation sector without imposing unpopular restrictions on transport. One of the first studies seeking to calculate the macro impact of ICT on transportation was a study prepared by Arthur D. Little in 1991. The study was very optimistic with regard to the potentials. The executive summary begins as follows: "Can telecommunications help solve America's transportation problems? The answer is definitely yes!" (Boghani et al. 1991) This answer is based on calculations of the savings, which can be realised through:

- Commuting to work substituted by "telecommuting"
- Shopping, substituted by "teleshopping"
- Business trips, substituted by "teleconferencing"
- Transportation of information, substituted by electronic information transfer.

The calculations estimate that a 33% reduction in transport can be achieved by use of telecommuting. Later studies are far less optimistic regarding the potential savings. One reason is that second order and third order impacts are taken into account (see below). Another is that diffusion of transport reducing ICT applications not has reached the expected levels[4].

Later studies have estimated savings at the level of 2-3%. A study of the impact from telecommuting and teleshopping in Denmark estimated the savings to be about 1% of the total person transport (Transportrådet).
This part of the analysis of ICT will try to analyse the reality of these aspects and try to reduce some of the uncertainty by introducing a couple of visions for different specific applications regarding the three areas, transport, logistics and mobility.

There are four different dimensions of the impact on the environment from the transport sector:

- Overall demand for transport by type
- Demand by transport mode
- Efficiency by mode of transport
- Environmental impact from different modes of transport

While the first two points mainly relate to the demand side, points three and four (in particular four) mainly relate to the supply side.

[4] Back in the 80's it was expected that as many as 40% of the employees could work as teleworkers (Korte 1988)

First, one must distinguish between freight and person transport as the ICT impact is very different for these two types of transport. For each of these the ICT impact on the overall demand must be assessed. Person transport is usually measured in person kilometres and freight in ton kilometres.
ICT can affect the overall demand in various ways: Different applications of ICT may substitute the need for transport for instance by use of telework or by use of e-mail instead of surface mail. But ICT may also generate new needs for transport. This impact will most often be realised through indirect effects, for instance through the impact of ICT on globalisation.

The overall demand for transport includes a wide range of very different transport needs with regard to location, speed, frequency etc. These different needs will often demand use of different modes of transport e.g. train, private car or flight. As the environmental impact from the modes of transport is very different, it is important not to assess the ICT impact on total demand only, but also the ICT impact on the demand for each mode of transport.
ICT is widely used to increase efficiency of transport through more efficient planning. This implies that more ton kilometres (and to a certain extent more person kilometres) can be realised per kilometre driven by a truck, sailed by a ship etc. and that more transport work can be carried out without increased impact on the environment.

Finally, ICT can be used for design of more environment friendly means of transport, e.g. less polluting cars and flights as mentioned earlier in this chapter. The impact of transport on the environment is a multidimensional parameter including a large number of different environmental factors such as noise, emission of NO_x's and CO_2 etc. However, this section will not address these parameters separately.

ICT penetrates all parts of our daily life and all parts of the production. It is therefore impossible to assess the environmental impact of every possible application of ICT, which affect our transport behaviour. A study on the ICT impact must therefore concentrate on a limited number of parameters. ICTRANS – an EU project on Impacts of ICT on transport and mobility makes a distinction between ICT applications within three different socio-economic domains (producing, living and working). Within each of these domains the most important ICT applications with regard to impact on transport are identified (table 3.7). It follows from the table that some applications affect transport behaviour within more than one socio-economic domain.

Table 3.7
Mapping application areas into socio-economic spheres.

Producing	Living	Working
Logistics services Manufacturing systems Customised services Retailing and distribution	Customised services Retailing and distribution Teleshopping	Teleshopping Distance working Self-employment

Sources: Impacts of ICTs on transport and mobility (ICTRANS) (ESTO 2003).

We have chosen to limit our analysis to three different applications:

- Transport logistics (surveillance, optimisation etc.)
- Telework (including telecommuting, teleconferencing a.o.)

- E-business (including teleshopping and B2B (Business-to-business))

These three applications are more broadly defined than those defined in the ICTRANS study and cover in our opinion the most important aspects of the ICT impact on transport behaviour within the three socio-economic spheres. As far as possible the analysis will include direct first order effects, as well as more indirect second and third order effects which will be presented in the following part of the report. The base for this discussion is desk research combined with a few interviews with different actors in Denmark. These actors are presenting both the areas of research and the developing business.

3.8.1 Telework

There are many different definitions of telework, some definitions take the technology as point of departure and focus on how of ICT is applied in the work process, while others see telework as a new way to organise the work (which brings telework close to the concept of distance work). Sometimes telework includes only working from home and sometimes it includes any work related use of ICT. We will in this project use a rather broad definition, which include all work related activities where ICT facilities are used to facilitate a change in location of work place.
This definition of telework includes at least six different categories:

- Telecommuting (working from home and thereby avoiding person transport to and from the work place)
- Teleworking centres (working from a telecentre and thereby reducing person transport to and from the work place).
- Teleconferencing
- Mobile teleworking
- Self-employed teleworkers
- Offshore teleworking

In addition to these categories e-learning could be added as a separate category (examples of e-learning is provided in the box below), as learning also may be a working activity. But in this context, it is more convenient to look at e-learning as a sub-category of some of the above categories. There is no reason to distinguish between e-learning from home and telecommuting and e-learning from the work place is, with regard to the impact on transport behaviour, very similar to teleconferencing.

Telecommuting is the most classical concept for telework. Telework includes employees working from home using some sort of telecom facilities to communicate with their work place. Working from home is not a new concept but has taken place for centuries, but use of telecom facilities has made it a much more flexible solution, which can be used for more purposes. Telework can be either part time or full time. Looking at statistics on diffusion of telework, it is important to take the definition of telework into account. It is common to define teleworkers as employees working at least one full day a week from home. But sometimes also employees working from home occasionally or only part of the day are included.

Examples of e-learning.
A master programme in Mobile Internet Communication is offered in a co-operation between two technical universities in Denmark. The two universities are located in different parts of the country and students are spread over a wide area. Therefore the classroom teaching is limited to a few intensive seminars, while the remaining part of the teaching is mediated via the Internet. Even during the seminars e-learning is applied, as video-conferencing is used in some of the lectures. This enables students to follow the lectures from both universities, and use of lectures located in other countries. Even the final examinations are conducted by use of video-conferencing facilities connecting the two universities.
(Master in Mobile Internet Communication – mMIC 2005)
For the past ten years, the IEEE (Institute of Electrical and Electronics Engineers) has met engineers' need for flexible and affordable materials through videos, CD-ROMs and self-study courses delivered to them by mail. The components of a typical IEEE Self-Study Course include a study guide, textbook, and final exam. These materials are structured to provide clear-cut learning objectives, self-testing opportunities and helpful information. It is expected that web-technology will be applied to provide this type of training in the future.
(IEEE 2005)

The concept of teleworking centres has in particular been used in US. Employees are allowed to do their work in a teleworking centre providing the similar facilities to those at the central office, but located in a shorter distance to the home of employees. The idea is to reduce commuting into the crowded city centres. Teleworking centres may be located in the suburbs, but telework centres has also been established in rural areas. Here the purpose is rather to foster regional development than to reduce transportation.

Teleconferencing includes on-line communication between two or more places of work. Most definitions of teleconferencing demand a video-link between the different locations. This application has so far not been very successful. The reasons for this have been that the technology has been expensive and inflexible. But this will change as broadband connections become more widespread, and it is possible to establish a video-link from the employees' own computers. It can be argued that the use of a video-link is irrelevant for a discussion of the impact of transport behaviour. But the idea is that a video-link enables types of communication that almost entirely can substitute traditional business meetings.

Mobile teleworkers are employees, which perform most of their duties outside their office. This could be sales people such as insurance agents or employees involved in repair and maintenance or after sale services. Such mobile workers use ICT to support their work and to reduce the need for visiting their work place once or twice a day.

Self employed teleworkers are self employed, who maintain a part of their business contacts by use of one or more of the above mentioned concepts for telework. This makes it possible to serve customers far away, which in particular is of importance for self employed located in remote rural areas. Finally off-shore teleworking should be mentioned, although the direct impact on transport behaviour might seem to be less clear cut than for the other categories. Off-shore teleworking includes out-sourcing of certain information intensive service functions to other areas. This could be routine jobs like ticketing and customer handling from call centres, but also more specialised consultancy services may be outsourced (UNITAD 2002). The relation to telework is that these types of out-sourcing necessitate intensive use of ICT for exchange of information and to become economically viable.

The direct impact of telework on transport behaviour is in both the living and the working spheres. 1) Telecommuting and 2) teleworking centres relate to the living sphere only, while 3) teleconferencing and 6) off-shore telework relate only to the working sphere. 4) Mobile teleworking and 5) self-employed teleworkers relate to the transport behaviour in both spheres.

3.8.2 Diffusion of telework

Estimations on the diffusion of telework vary considerable depending on the source. Although it must be expected that the numbers of teleworkers are growing, some of the most optimistic estimations dates back to the early 80's. At that time it was foreseen that as much as about 50% of all office workers would be teleworking.[5] The most recent estimates are much more modest as they shows that 13% of the work force in EU15 was engaged in some sort of telework in 2002 (compared to only 6% in 1999). Out of these 7.4% are home based. The potential seems however to be considerable larger as two thirds are interested in either occasionally or permanent to work from home according to a ECATT survey from 1999 (Hommels et al. 2002).In the 90s teleworkers were mainly belonging to the higher echelons of the labour market, but following substantial reductions in prices for establishing teleworking facilities more groups are using this opportunity. Table 3.8 shows an international distribution of different types of telework.

Table 3.8.
Types of telework (in %). Base: All persons employed (N=5,901), weighted; EU averages weighted by EU15 population (SIBIS 2002).

	All home-based teleworkers	Home-based teleworkers alternating/ permanent	Mobile teleworkers	Self-employed teleworkers in SOHOs[6]	All teleworkers (excluding overlaps)
AUSTRIA	6.7	2.0	3.7	5.7	13.8
BELGIUM	7.5	2.2	2.4	2.5	10.6
DENMARK	17.7	2.6	2.7	2.9	21.5
FINLAND	15.7	4.7	6.2	3.2	21.8
FRANCE	4.4	2.2	2.1	0.8	6.3
GERMANY	7.9	1.6	5.7	5.2	16.6
GREECE	6.0	2.1	3.5	3.4	11.1
IRELAND	6.0	0.5	4.2	3.3	10.9
ITALY	2.5	0.8	5.5	2.6	9.5
LUXEMBOURG	3.3	0.9	1.5	1.8	5.6
NETHERLANDS	20.6	9.0	4.1	5.0	26.4
PORTUGAL	1.6	0.5	0.3	1.5	3.4
SPAIN	2.3	0.3	0.8	2.0	4.9
SWEDEN	14.9	5.3	4.9	2.0	18.7
U.K.	10.9	2.4	4.7	4.5	17.3
EU 15	7.4	2.1	4.0	3.4	13.0
CH	11.4	4.2	7.6	2.2	16.8
USA	17.3	5.1	5.9	6.3	24.6
BULGARIA	3.6	1.5	1	1.2	5.5
CZECH REP.	1.4	0.1	2.1	1.6	4.7
ESTONIA	7.8	3.7	3.9	1.8	12.2
HUNGARY	0.8	0.6	0.9	2.1	3.6
LATVIA	3.1	1.1	2.4	1.5	6.5
LITHUANIA	7.6	2.3	n.a.	1.5	9.2[4]
POLAND	4.9	1.0	1.0	2.8	8.4
ROMANIA	1.1	0.3	0.6	0.3	2.0
SLOVAKIA	0.9	0.5	1.8	1.6	3.7
SLOVENIA	4.4	1.6	3	2.3	8.6

[5] An overview of estimations of numbers or percentage of teleworkers is provided in Anique Hommels (et al. 2002)
[6] SOHO = Small office/home office

Denmark is well above average as 21.5% are teleworking (17.7% all home based). These figures build however on a very broad definition of telework. A survey conducted by Danish Technological Institute indicates that there are very few teleworkers working a full working day from home in Denmark (Int. Schmidt 2005). In Denmark a tax incentive for companies investing in homebased PCs to the employees have had a significant impact on the number of teleworkers. Moreover telework in Denmark telework is usually considered as a basic labour right, while introduction of telework in most other European countries is introduced only if it can be justified in financial terms (SusTel 2004), this makes it difficult to make exact estimates on the number of people using telework on a regular basis. One example is TDC where it is a part of the staff policy to offer teleworking facilities (see box).

Teleworking at TDC.
TDC is one of the most advanced Danish companies with regard to use of telework. New staff members have access to teleworking facilities from their first day in the office. For service technicians use of telework facilities is an integral part of their daily working routine (Int. Schmidt 2005).

Home based teleworking seems to be surprisingly low tech (SusTel 2004). This could indicate that today growth in telework is more a question of development in management culture and organisation than a question of technical development of new communication facilities. It should however be noted that costs of ICT may be an important parameter. For instance will a decline in prices for broadband connections open up for more advanced use of ICT facilities by teleworkers, and thereby enabling more functions to be carried out from home.

One of the most important limitations for a wider user of telework is that knowledge sharing – in particular sharing of tacit knowledge – is more complicated among distant workers. Technical solutions addressing this problem may be developed. This could be done for instance through provision of high quality video communication or other tools facilitating informal communication between colleagues.

3.8.2.1 Impact on transport behaviour in the sphere of living

The factors affecting transport behaviour can be summarised as:

Table 3.9
Types of environmental impact of telework on transport behaviour in the sphere of living.

First order effects	Substitution: The level depends on the number of telecommuters, the frequency of telecommuting and the distance between home and work place (or telecentre) Urban sprawl: reduction in rush our traffic
Second order effects	Short term: • Impact on non work related transport • Impact on transport behaviour for other members of the household. Long term: • Reduction in number of private cars • Changes in habitation • More flexible labour market (and hence large commuting distances)
Third order effects:	• Impact on development of public transport • Impact on localisation of work places • Impact on tegional development

Substantial efforts have been made to quantify the transport impact. In particular the substitution effect has been calculated in a large number of studies. Most studies foresee a reduction between 1-3%. According to Mokhtarian, many of the studies tend to overestimate the impact as they do no include second order and third order effects. She estimates the effect to be less than 1% of the total travel miles (Mokhtarian et al 2002). A Danish study from 1996 estimates the potential impact in Denmark to be 0.7% (Transportrådet). This figure is confirmed by a more recent unpublished study by Danish Technological Institute (Danish Technological Institute). However, if homeworking (working from home without use of ICT facilities is included) a much higher impact can be obtained.

The short term third order effects (also called the rebound effect) have been included in a study made as part of the EU funded SUSTEL project. This study indicate that a substantial part of the transport savings are nullified by increased transport for other purposes such as shopping and increased transport by other family members. The latter is particular relevant in one car families.

Table 3.10
Commuting reductions and rebound effect.

	Denmark	Germany	Italy	Netherlands	UK1	UK2
Reduction in weekly commuting (km)	105	283	242	98	253	61
Addition travel (km)	77	53	33	42	60	15
Rebound effect in %	73	19	14	43	24	25

Note: Two case studies were carried out in UK (SusTel 2004).

3.8.2.2 Impact on rush hour traffic and modality

Commuting is characterised by its regularity: It goes to the same destinations at the same time every day. Commuting is the major source for urban sprawl in the rush hours. Increasing use of telework from home will provide more flexibility to the commuters so they will be in a better position to avoid rush hours. Telework will therefore imply a more equal distribution of the load of person traffic during the day. This will lower problems related to crush during rush hours, but may also add to more traffic in person cars, as this may be the preferred mode of transport outside rush hours.

Telework may imply that people will accept to travel longer distances or on routes not covered by public transport services once they need to visit their work place. Both will add to less use of public transport services. This is illustrated by the fact that public transport has a market share above average in commuting related transport purposes.

3.8.2.3 Impact on transport behaviour in the sphere of working

The factors affecting transport behaviour can be summarised as:

Table 3.11.
Environmental impact of telework on transport behaviour in the sphere of working.

First order effects	Substitution: The level depends on the number of business trips it is possible to substitute and the length of the trips.
Second order effects	More intensive communication with current business partners Extension of business networks More outsourcing and specialisation
Third order effects	Out-sourcing and globalisation of production. Internationalisation of markets Impact on localisation of work places Impact on regional development

The impact of transport behaviour in the working sphere is much less studied than the impact in the private sphere. One reason may be that with regard to personal transport commuting is seen as the major transport problem - not so much because of its dominant role in the total transport – but rather because it is the major cause to urban sprawl during rush hours. Another reason is that it is much more straightforward to calculate the substitution impact with regard to telecommuting.

Business trips are not as regular as commuting trips and will often be longer than commuting trips. It is very difficult to estimate the potential for substitution. In particular if this potential is defined as additional substitution compared to what is done today. Communication between businesses takes many forms including use of low tech solutions such as letters and phone calls, and a video conference may be a substitute for these types of communications as well as for a business trip. The above mentioned study from Arthur D. Little, is one of the few attempts to estimate the substitution effect. Here it is assumed that 13-23% of all business trips may be substituted. This includes transport related to learning activities.

Technology is important for the rate of substitution. It is clear that teleconferencing still is in its infancy. In 2000 only 12% of establishments with EU used videoconferencing (Empirica 2000). Development of teleconferencing tools creating a virtual environment providing the right facilities for exchange of information will affect the amount of business trips that may be replaced. In certain areas also implementation of ICT based system in production and management will affect the possible rate of substitution. One example is air maintenance. In this case most of the necessary information is stored in a digitized format, and maintenance and repair decisions can therefore be taken without physical presence of aviation experts. In the same way it may possible to operate robots used for medical operations.

E-learning can be implemented by use of e-mail only, but distant conduction of lectures and oral examinations demands more sophisticated ICT applications.

The transport implications of mobile teleworking are rather different from those for home based teleworking. Like home based teleworkers mobile teleworkers may avoid commuting to their work place, but they may increase transportation during working hours. A study by BT in which most teleworkers were mobile teleworkers indicates that the total transport work may increase. 18% of the respondents stated that their in work travel increased by an average of 267 miles per week, while 9% stated that it decreased by 394 miles.[7]

3.8.2.4 Long term perspectives

Telework does not require use of advanced ICT technologies, but new technologies may open-up for new applications of telework. In the short term mobile technologies will be the most important. 3G will enable more mobile applications of data transfer and video, making it easier to connect not only from home but also from any other location. Security will also be a crucial parameter, as companies still may be hesitant to enable access to sensitive information from outside. In the long term development of high quality video communication offering virtual reality like alternatives to physical presence may be developed, among others, to facilitate informal knowledge sharing. The long term impact will, however, also depend on how the conditions for personal transport evolve. Development of alternatives to physical presence will depend on how difficult it will be to make use of physical presence. If transport is both expensive and time consuming electronic alternatives are more likely to be developed.

3.8.3 E-business

The concept of e-business covers a wide range of business activities with very different implications for transport and the environment. E-business may include any business activity using ICT. According to this definition, all other applications of ICT analysed in this chapter could be termed as e-business activities. In this section, we will however limit ourselves to discuss the transport implications of use of ICT for external activities related to exchange of goods or information with suppliers or customers. This limitation brings us close to the concept of e-commerce. However e-commerce includes only commercial activities and most public services is therefore excluded from this definition. Even with this delimitation it is necessary to distinguish between different types of e-business. First of all one may distinguish between business to consumers, B2C, and business to business, B2B. Some also makes a distinction between businesses and governments (G2C and B2C etc.), but this distinction is not essential in a study of transport implications.

On the other hand it is important to distinguish between exchange of tangible and intangible goods, as the first category involves transportation of goods, while intangible goods may be exchanged over the telecom network without any implications for transport behaviour.

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[7] SusTeL Op.Cit.

Third, we will make a distinction between applications of ICT in different phases of the business process. We will here use a simplified version of Porter's value chain model (Porter 2001):

- Before sales: Activities related to identification of providers or customers and services/products to be acquired.
- Sales: Processes related to the sales transaction such as payments, delivery, signing of contracts etc.
- After sales: customer support, maintenance etc.

Teleshopping and to a certain extent e-business tend to focus on the sales process itself, but after sales and in particular before sales are equally important functions – also with regard to transport implications.
E-business affects both the working and the living spheres. B2B will mainly affect the working sphere, while B2C affects both living and working.

3.8.3.1 Business to Consumers

E-business in relation to consumers is in reality the same as teleshopping. Teleshopping is not an entirely new concept. Similar ways of distant shopping has been carried out without use of advanced ICT. Mail order has been used for decades and ordering by phone is also a well established way of shopping. However, the Internet and a wider penetration of broadband have enabled a dramatic increase in the potential for distant shopping.
The benefits of teleshopping for consumers are:

- More convenient shopping
- Timesaving
- Savings in transport
- Faster delivery
- More transparent markets
- Better market access
- Periphery regions/developing countries
- Physical impaired
- More competition

More transparent markets are in particular related to before sales processes, where different products and suppliers are compared. This can be done much faster and without any person transport. This may however imply that the consumer becomes aware of suppliers located long away. If the actual purchase is done in the traditional way, the transport savings achieved through electronic scanning of the market, may therefore be nullified through more transport in the sales process.

One of the major barriers towards teleshopping has been establishment of efficient distribution systems. Teleshopping has therefore been particular successful in areas, where the goods either can be transmitted via the telecom network or where they can be delivered via the existing postal mail systems.
A study by the German Ministry for Transport lists the following effects of teleshopping on traffic (see table 3.12). The list was made through a survey of a large number of German studies. The list implies that B2C is foreseen to have a wide range of impacts on transportation, both on the overall levels of freight and person transportation, and on the structure of the transport. It is however difficult to derive any firm conclusions on whether transport will

increase or be reduced, in particular if second order and third order effects are included.

Table 3.12.
List of impacts on transport behaviour from B2C:

• B2C will result in the increase of small-part sendings to an increased number of end-customers with individual delivery-places and delivery-times.
• B2C-traffic will concentrate on suburban areas.
• B2C induces more courier, express and packet deliveries
• B2C will lead to inhomogeneous transports in urban surroundings and at the same time to a better consolidation of long-distance traffic.
• Storage concepts, distribution and collecting traffic have to be adapted.
• Comeback tours of delivery vehicles will produce additional traffic.
• Some shopping trips will be replaced by deliveries.
• Applying logistic concepts can result in package effects (less single traffic).
• In-time deliveries are always price sensible and will almost always lead to street traffic.
• Trends in courier, express and packet (cep) deliveries (ongoing trends but supported by increased online-shopping).
• Cep-services will require more small vehicles.
• The total number of tours will increase.
• Cep-traffic will mainly affect suburban areas (housing areas).
• Delivery drop-offs (pick-up stations) will be asked for in suburban living areas.
• Because of the increasing transport of small-parts, other transports will be substituted
• Speciality transports like grocery deliveries will remain a niche market.

Source: (Zoche et al. 2002)

B2C will increase transport related to delivery of goods and change the structure towards smaller units, but this does not necessarily increase the total needs for transport. According to an American study, best-selling books by e-commerce has a smaller impact on the environment than traditional delivery (Matthews et al. 2001). Also a Swedish study indicates that e-commerce not necessarily will lead to more traffic (Fichter 2001).

In the long term a wide penetration of teleshopping may add to the ongoing centralisation of the retail market, which may imply that both shopping trips and e-shop deliveries will involve longer transport distances.

Table 3.13.
Environmental impact of e-business on transport behaviour in the sphere of living.

First order effects	Substitution of transport related to market scanning. Substitution of transport with intangible goods. Substitution of person transport with delivery of goods. Change in freight transport towards smaller units.
Second order effects	Extended range of local consumer markets
Third order effects	Centralisation of shopping facilities Some services only available on-line

3.8.3.2 Business to Business

Business to business applications include a number of activities, which hardly can be distinguished from activities included in the section on telework (e.g. e-learning). Use of ICT for business to business trading transactions has taken place for at least 20 years. Large enterprises have used EDI (Electronic Data Interchange) for communication with their main business partners for many years. However development of these systems were often hampered by lack of standardisation and were mainly used in closed networks confined to a limited number of regular business partners. Use of EDI demanded substantial investments and many SMEs have been reluctant to use EDI unless they were forced by major costumers such as retail chains.
The Internet and the IP-protocol has provided a low cost solution which is used for common platform for many types of electronic data transfer. This

has enabled a much wider use of electronic networks for business transactions. The Internet has however, not replaced the former trading networks, which often are considered to be more secure and reliable.
The key drivers in B2B can be summarised as:

- Globalisation, an increasingly transnational purchase and selling process
- Application of ICT in enterprises to lower transaction costs
- Availability of more sophisticated IT-infrastructures, almost all enterprises are mapped by computer systems
- More demand for personalised individually manufactured or combined products (Zoche et al. 2002).

Thus B2B has facilitated the ongoing trends of globalisation and out-sourcing by lowering transaction costs and make them less dependent of distance. The transport implications of B2B applications are more complicated to assess, than the implications of B2C applications. The person transport related to business trade is not always directly related to the transaction itself, and may be difficult to distinguish from other types of business trips. Therefore the most important implications are related to how business trade is done: Use of e-business will reduce transaction costs per transaction and will therefore tend to increase the number of transactions. This will lead to changes in freight transport towards smaller batches. In addition to this it will be less costly to maintain business relations to a large number of companies and enable more use of out-sourcing.

Table 3.14.
Environmental impacts of Business to Business.

First order effects	Substitution of business trips related to market scanning. Substitution of transport with intangible goods. Substitution of person transport with delivery of goods. Change in freight transport towards smaller units.
Second order effects	Extension of supplier and customer networks Increasing use of out-sourcing
Third order effects	Development of just-in-time delivery networks for small batches Erosion of infrastructure for bulk transport Internationalisation of markets

3.9 Transport logistics

Transport logistics is usually mainly related to freight transport, but application of ICT can also be used for optimisation of person transport. Transport logistics include:

- Transport planning – when and where transport is needed
- Route planning – finding the optimum route
- Modality planning – identifying the optimum mix of modalities
- Radio frequency identification systems
- Speed control systems

Transport planning is closely related to planning of production and storage. ICT has played a major role for instance in introduction of Just-in-time production systems. These have profound implications on transport needs in the direction of more frequent and smaller batches. The analysis is, however limited to implications of use of ICT in distribution and is not going into further details with regard to the transport implications of production technologies and strategies.

Implications for the environment of more efficient speed control are difficult to assess. In some instances speed control may even increase fuel consumption as the speed limit is set below the optimum speed with regard to fuel economy. Speed control will therefore not be discussed further.
In addition to the above mentioned issues, ICT is used for support of public policy – for instance in analysis of traffic loads by hour and location and forecasts of implications on traffic behaviour by changes in infrastructure supply (e.g. a new railroad, changes in tariffs etc.).

Finally, use of ICT is an important element in provision of road pricing as a policy tool for transport management.

3.9.1.1 Route planning

Route planning can be used to make transport more efficient. Route planning systems can if integrated with other administrative systems both reduce mileage related to driving certain routes, and contribute to a higher utilisation of loading capacity. Route planning systems are today used mainly in freight transport. The drivers for investing in such systems are cost reductions related to better utilisation of resources (vehicles, fuel and drivers). Aeromark (see box) see their major customers to be companies with a fleet of at least 20-25 vehicles. This could be freight operators but also companies with their own fleet of vehicles. It is foreseen that route planning systems will become standard within all types of trucks and vans used for freight transport. Route planning systems are also used by mobile workers e.g. in domestic services (see box).

Many person cars have already today implemented simple route planning devices such as digital maps; these are expected to become more widespread in the future.

Aeromark.
Aeromark is a technology based company in the UK and Denmark established in 1985, specialising in the provision of complete mobile voice and data solutions for corporate and SME business users throughout Europe.
The company provides complete ICT solutions for fleet management including communications infrastructure, terminals in trucks and office systems. The system enables tracking, route planning, surveillance of fuel consumption and communication with the driver (voice, SMS and data exchange). Development and system design is made in Denmark while adaptation to particular customer needs is done in the UK.
Tracing of vehicles is a standard technology provided by a large number of companies. Such systems can be bought at 350-800 € per vehicle. Aeromark is however the only providing total integrated solutions in Denmark, while there are 2-3 competitors in the UK. The Aeromark solution costs about 4,000 € per vehicle.
The major drivers for the development have been a need to optimize transport and use of utilisation of resources, and safety.
Sources: (Int. Aeromark 2005) and (Aeromark 2005)

Route Planning for Homecare services.
A number of city councils at Zeeland have together with enterprises and organisations created a company called Zeeland Care developing products for handicapped. The company has in cooperation with Center for Traffic and Transport at Technical University of Denmark developed a route planning system for home care services in order to reduce travel time for home carers. (Int. Madsen 2005)

Route planning systems can also be used to facilitate alternatives to individual transport by car. Use of collective means of transport may benefit from tools such as 'Rejseplanen', which enable users better to plan their journey. More flexible types of collective transport, such as tele-busses (unscheduled busses serving customers on request), may benefit from use of ICT based systems. The same goes for car pooling and car sharing services.

In the future route planning may include ‘intelligent roads’, where route planning systems take the current load of traffic into account, and ensure optimise usage of road capacity instead of directing all cars to use the same routes.

3.9.1.2 Modality Planning

Trucks are often the preferred mode of transport for freight. One of the reasons for this is that trucks can provide end-to-end delivery, while ship, car or flight transport often needs to be combined with other modes in order to provide the same service. Multi-modal transport is often avoided because of the need for more complicated logistics compared to what is needed for single mode transport. Use of ICT for improvement of logistics may therefore facilitate use of multi-modal transport.

The ideal would be to have one single route planning model enabling use of different modes of transport like ‘Rejseplanen’ used for public transport by persons. Such a model would however be far more complicated than ‘Rejseplanen’. It would involve many more actors and it would involve use of unscheduled services. In addition to this, it would be necessary to be able to optimize with regard to a combination of a number of different parameters such as price, speed and capacity.

Center for Traffic and Transport (CTT) at Technical University of Denmark is working on solving these problems. They have received support from the Danish Højteknologifonden and the EU for doing research in this area (Int. Madsen 2005). CTT is one of the leading research centres in this area, but major work is also done in Canada. The major driver for this work is not environmental concern but rather a concern for crush on the highways and in the major cities. In particular after inclusion of the Eastern Europe into the EU, it can be foreseen that there will be even more capacity problems on the German highways, and it is therefore essential to promote use of railways for freight transport.

In addition to multi-modality planning models, multi-modality can also be facilitated by use of smaller models improving efficiency at freight terminals. Such models can make modality shifts more efficient, for instance by optimising shunting of goods wagons. Airport terminals are the most advanced in the use of such models. Maersk operates a number of harbours, but they are not yet using such systems for this purpose.

3.9.1.3 Radio Frequency Identification Systems

Radio Frequency Identification (RFID) can be used for tracking of freight items. This can improve transport logistics as it provides information on exactly where a specific item is located. Use of RFID for transport logistics was first introduced by US under the first Gulf war. Sweden is among the leading countries in this area. In Denmark, Easy Cargo has tried to introduce RFID as part of their services. Use of RFID may in particular benefit multi-modal transport, as tracking is less important for the logistics of single mode end-to-end transport systems.

3.9.1.4 Road Pricing

Road pricing is probably the ICT application within transport, which attracts most attention from the public. Road pricing provides an alternative to more traditional taxation systems and aims at influencing transport behaviour. In particular road pricing is an alternative to payment of tolls when entering highways or major city areas. By use of road pricing it becomes possible to tax exactly those types of transport that it is considered to be important to reduce. It is possible to distinguish both between different routes and different points of time. So far road pricing has been introduced only for trucks in Germany. The drivers for introducing road pricing are both environmental concern and reduction of crush.

3.9.1.5 Implications for transport behaviour

The factors affecting transport behaviour can be summarised as:

Table 3.15.
Environmental impact of ICT logistics on transport behaviour in the sphere of producing.

First order effects	Efficiency gains in particular in multi-modal transport
Second order effects	Growth in transport demand Multi-modal and public transport will gain market shares as a result of efficiency gains and road pricing
Third order effects	Out-sourcing and globalisation of production

Use of ICT for improved transport logistics will first of all improve efficiency of transport. Whether this will lead to less or more transport depends on supply and demand conditions, including costs. More efficient transport could lead to a higher demand. As the efficiency gains particular will be related to multimode and public transport, transport logistics must be expected to have a positive impact on their share of the total market. This trend can be further strengthened through introduction of road pricing. There are, however, other trends that work in the opposite direction, first of all the increasing demand for transportation of small batches.

3.10 Long term perspectives for innovation and regulation

This section summarises the analyses in the previous sections of the chapter and raises some issues in relation to the future dynamics in the interaction between ICT and environment, as how it is shaped in interaction with other aspects of societal development. Also the interaction between regulation and innovation is summarised.

The ICT sector in Denmark can be characterised by the following business and research related strengths:

- A strong position in the communications technology (including mobile, wireless and optical communication)
- A strong position internationally in global ICT/pervasive computing with competencies in embedment, system integration and user-oriented design
- Denmark is one of the leading countries regarding the use of ICT by the citizens, business and the public sector.

The analyses have focused on five areas or fields of ICT application:

- Improving environmental knowledge.
- Design of products and processes.
- Process regulation and control.
- Intelligent products and applications.
- Transport, logistics and mobility.

All five areas show future potentials for environmental improvements, but the analyses also indicate that none of the five areas automatically imply realisation of environmental potentials. New and reinforced risks are also an expected impact of the development. An increased amount of electronic products and a more dispersed amount of sensors and other devices imply increasing problems with electronic waste. Increased use of pervasive computing might also cause health problems due to electro-smog from increased electromagnetic radiation and safety problems due to interference between different devices operating in wireless networks. There is need for research into these risks, which are not fully understood and which might be long term effects, which call upon the use of precaution as an important principle in the development and application of ICT.

The first order effect from a bigger and more disperse amount of ICT-equipment could be reduced through governmental regulation of the use of hazardous chemicals and energy and material consumption. Efficient implementation of the EU directives about waste, energy consumption and hazardous substances are important for the future development of the first order effect. Miniaturisation of products might not imply reduced resource consumption since the smaller dimensions can demand higher quality of materials, which implies more processing and maybe higher amounts of waste.

There are potentials for environmental improvements from the application of ICT-based tools for data collection and processing, product and process design, and process regulation. However, today environmental concerns are seldom the driving force for the development and application of these devices and tools. More data processing capacity enables the processing of more data and more complex calculations, but it is the aim of the application that determines whether environmental achievements are obtained. The interviews have shown one case of direct integration of environmental criteria into tools for product and process design. Other tools aim at more general resource efficiency, probably often determined by the prices for energy and materials. It was stressed at one of the project workshops that governmental regulation is the only strategy for getting environmental aspects and concerns integrated into the development paradigms.

The case about the product development paradigms for vacuum cleaners shows that the biggest reduction in energy consumption might not be achieved through the development of products with sensors and more electronic equipment (more intelligent products). In stead focus could be on a change in the market dynamics through a combination of eco-labelling and design of new product concepts with a basic focus on understanding and improving the operation and the efficiency of the existing products and the service the user obtains.

The case about the intelligent automobile shows how complex the interaction between ICT and environment can be. A product like a car is not just an energy efficient engine, but consists of a combination of a number of technologies, which implies that the final product might not be more efficient. Furthermore is the role of a more energy efficient product shaped by a lot of actors and dynamics. The governmental regulation has impact on the price of the product and the price of the energy. The societal and local dynamics in housing, employment, infrastructure etc. has a big impact on the actual purchase and use of products. Furthermore is the need for example for transport not a fixed need, but is shaped by the availability of the product, so

the access to the product, in this case a car, influences the development of the need for transportation. This case shows, like the case about design and optimisation of products and processes that governmental regulation is needed in relation to all phases of innovation: the choice of research strategy, the innovation of products based on combinations of technologies and the development of the market dynamics around the products. It is not a phase-by-phase regulation that is needed, since innovation dynamics and focus also is determined by actual and expected market demand. This argument has been stressed several times at the innovation workshops in the project.
The environmental aspects of the ICT-development depend also on the development in the total stock of products. This implies that development of new products that are lighter, faster etc. do not give a reduction in the energy and material consumption if the stock or fleet of products increases or only a partly substitution takes place.

The three application areas for use of ICT in transport, which have been analysed, are considered to be those implying the most far reaching implications for transport behaviour also in the long term.

New technological achievements will create new opportunities for use of ICT either to increase efficiency or to substitute transports. However, the basic applications will be very similar to those of today.

Most teleworkers are using low-tech solutions for solving their communication needs. This could indicate that technology is not a barrier for further development of teleworking and that technological innovations only will play a minor role. But one can also argue that the reason is that more advanced technology solutions are too expensive for a teleworker and that provision of broadband access at affordable prices will promote use of more advanced types of communication, for instance video-conferencing. Use of high quality video will enable many job functions, which today demand physical presence, to be carried out as telework. Physical inspection of aircrafts and medical consultations are just a few examples of this.

High quality video may also be a solution on one of the most important barriers towards full time telework, namely knowledge sharing. Without physical presence it is difficult to develop neworks for informal exchange of information and tacit knowledge. If electronic communication is made more flexible and provides a better quality, physical presence may become less important.

Still the expected growth in telework will mainly derive from socio-economic changes: Still more people are employed in job functions suitable for telework (partly as a result of use of ICT), and new management cultures based on self-leadership become more widespread. In addition to this the average travel distance between home and work place is growing due to the development in housing costs and the centralisation of business activities to fewer and bigger plants. It is, also in the future, a limited amount of employees, who might be able to telework due to the type of work they do, like manufacturing, cleaning, social care etc.

Mobile telework will be more widespread as mobile communication solutions will offer the same facilities at comparable costs as those offered from the office. This will reduce the costs of business travels (as lost working time today constitute a major part of the costs), and may therefore cause an increase in the transport related to this purpose. This means that the first order effect is positive, but the growth in demand for communication derived from globalisation of production and a growing need for training provided internationally will work in the opposite direction.

The long term impact of e-business depends very much on how e-business will develop in the future. Also with regard to e-business, the general opinion is that the major barriers are not related to development of suitable ICT applications, but to organisational problems and development of viable business models. E-business could, if combined with telework, in theory imply a dramatic reduction in transport needs, as people could do both their work and their shopping from home. The question is whether it is likely that e-business will provide a viable alternative to daily shopping. So far transportation has been a major barrier for electronic trade with tangible goods, which are unsuitable for delivery by mail.

Improvement in transport logistics will in addition to its impact on the current traffic behaviour also be important for the success of many types of e-business. Some scenarios for the future information society include creation of an infrastructure for delivery of daily necessities. If this ever will materialise, it will have a major impact on transport behaviour and could imply a bigger amount of transportation for distribution to households. Although the three application areas studied have very different implications on transport behaviour, they will all add to situation with more flexibility in transport. This holds in particular for person transport in the socio-economic sphere of living. The regular transport related to commuting and shopping in certain hours will be replaced by more differentiated transport needs, where some people will be able to avoid rush hours and the most populated routes. This will enable a better utilisation of the transport capacity for person transport.

However, the needs for person transport will also become more dispersed. First, commuting will take place less frequent. Second, the possibilities for telework will enable more people to live in remote rural areas. This will challenge the existing infrastructure of public transport, and tend to strengthen individual transport solutions, unless ICT is used to develop new types of more flexible public transport.

The impact of ICT on person transport behaviour will to a wide extent depend on developments in transport policies. Therefore policies promoting e.g. telework will probably have only a limited impact on the overall demand for transport, if not accommodated by other types of policies aiming at reducing transport needs. Decisions regarding the choice between electronic communication and person transport depend on the effectiveness of the two alternative forms of communication as well as their price. So far the costs of transportations have not been high enough to make reductions in transport a key parameter in development of telework or e-business. Most teleworking is implemented for reasons of flexibility and time saving rather than in order to reduce the amount of transport. This is illustrated by the fact that teleworkers seldom work at home full working days.

With regard to freight transport the situation is a bit different, as improved logistics will enable more flexibility. On the other hand will e-business, in combination with just-in-time production, lead to more transport of small batches with high urgency. Also in this case, transport policy is crucial for the net impact on transport behaviour. Reductions in transport are only happening if it leads to either reductions in the total costs or it increases flexibility.

Transport policy does not only play a role for the immediate ICT impact on transport behaviour, but is also important for the direction of new technological innovations. As long as fast transport is available at cheap prices, private companies do not have any incentive to develop or implement transport-reducing technologies if not combined with other benefits.
ICT does however also provide new policy tools within the areas of transports, first of all road pricing. Road pricing enables the design of economic incentives for reduction of transport in order to address exactly those types of transports where reductions are most urgently needed.

4 Environmental perspectives within biotechnology

Annegrethe Hansen & Henrik Wenzel

4.1 Introduction

Since the first successful genetic modification with a commercial viable technique in 1973, biotechnology was predicted an industrial future within a number of industrial areas: chemical industry and pharmaceuticals, food and beverage industry, energy production and agriculture.
The optimistic technical and economical prospects were put forward by both researchers and industry.

The aim of the research within biotechnology has been:

- To analyse how biotechnology and environmental perspectives have been conceived
- To analyse the future environmental potentials and risks within some areas of application for biotechnology, where environmental perspectives have been formulated
- To assess the role of environmental concerns in research, innovation and governmental regulation related to the areas of biotechnology application

As a generic technology, biotechnology was considered important for the competitiveness of industry and thus attracted political attention. A large number of countries from the late 1970s and especially through the 1980s introduced R&D programmes to stimulate new biotechnology developments. Resources primarily went to pharmaceutical and chemical R&D, although perspectives also were assumed for the other areas mentioned above. However, fewer resources went into these other areas, and R&D concerning positive environmental perspectives or negative consequences, was not high on the list either It was assumed that there were large potentials especially within pharmaceuticals and medicine, and the majority of funding, private and public went into 'red biotechnology'[8]. Universities and dedicated biotechnology companies, as they became known as, invested in the new biotechnologies, and large pharmaceutical companies followed, either with

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[8] There are number of jargon terms for sub-fields of biotechnology, here from (http://en.wikipedia.org/wiki/Biotechnology#Sub-fields_of_biotechnology).
Red biotechnology is biotechnology applied to medical processes. An example would include an organism designed to produce an antibiotic, or engineering genetic cures to diseases through genomic manipulation.
White biotechnology, also known as '\grey biotechnology', is biotechnology applied to industrial processes. An example would include an organism designed to produce a useful chemical.
Green biotechnology is biotechnology applied to agricultural processes. An example would include an organism designed to grow under specific environmental conditions or in the presence (or absence) of certain agricultural chemicals.
Green biotechnology tends to produce more environmentally friendly solutions than traditional industrial agriculture. An example of this would include a plant engineered to express a pesticide, thereby eliminating the need for external application of pesticides.
The term **blue biotechnology** has also been used to describe the marine and aquatic applications of biotechnology, but its use is relatively rare.

own investments in new biotechnology activities or by buying into a number of the new biotechnology companies and into university research.

The new biotechnologies offered opportunities for the production of new pharmaceutical products without the use of scarce resources or with the use of fewer resources, or using more efficient techniques.

The green biotechnology, primarily addressing agricultural applications and primarily changing the traits in agricultural or horticultural crops, has been an area expected to overtake the pharmaceutical area with regard to long-term economic impact. The expected traits were predicted as improving the plant with regard to yielding or enduring certain growing conditions, thus making the plants herbicide resistant. So far, herbicide resistance is still the major trait, with an increasing share of the GM cultivated area, consisting of herbicide resistant crops.

The main arguments for the development of GM-plants have been efficiency, including losses due to pests and weather, and the exploitation of more land for agricultural crops. Environmental advantages have, however, also been argued, primarily by the chemical and seed industry, but also by parts of the research community, parts of the farming community and parts of the governmental system. Environmental arguments were stated especially in relation to the herbicide resistant crops. The potential advantages concerned s the possibilities of reducing the number of herbicide sprayings and as the possibility to spray later, consequently reducing herbicide application and prolonging the lifetime of the weeds and thereby also the lifetime of the animals and insects living on them.

The environmental concerns regarding genetic engineering had been discussed since the first modifications in 1973 and throughout the 1980s. The regulation of the contained use of genetically modified organisms led in most of the industrialised countries to a relatively large acceptance of industrial production on the basis of genetically modified organisms. Though accidental leaks did happen, there was a general confidence among regulators and NGOs that production as well as accidents were controllable.

Genetic modification of plants, primarily for agricultural and food production, has been termed “the second generation of biotechnology” and green biotechnology. R&D in plant agricultural biotechnology increased in the 1980s within a number of different application areas. The dominant applications were the development of herbicide resistant crops, primarily soy beans, corn and cotton. In Europe, research was carried out on an increasing number of other traits and plants in the 1990s, but the area with herbicide resistant plants increased, both in absolute and in relative terms.

Environmental consequences were, and still are the main concern with regard to genetically modified plants. A number of NGOs and researchers raised concern and criticism during the 1970s, and this concern and criticism has been continued, with increasing international cooperation between many of the NGOs on documenting and forwarding the concerns for:

- increasing use of herbicides
- diffusion of traits, amongst other herbicide and pest resistance, from which follows concerns with regard to

- risk of the need for stronger herbicides to combat ao. weeds with resistance
- erosion of wild life,
- intoxicating and altering animal/plant life, and
- turning herbicide resistant crops into weed for other crops

Only few concerns have been repudiated, and different conclusions are drawn when weighing benefits and negative consequences against each other.

The white biotechnology (Webster, 2001) is primarily used about 'biotechnology applied to industrial processes' (http://www.websters-online-dictionary.org/definition/english/Bi/Biotechnology.html), and is, as previously mentioned, also termed as the third generation biotechnology. The white biotechnology were introduced to distinguish some of the industrial biotechnologies from the 'red biotechnology' representing biotechnology in medicine and in pharmaceuticals, from 'green biotechnology' representing plant biotechnology, and from the 'blue biotechnology' representing marine and aquatic applications of biotechnology.

The term white biotechnology is of newer date (around 2000), with NovoNordisk A/S, Novozymes A/S and EuropaBio (EuropaBio, 2003) being rather active in promoting the term. Forerunners of the term may be industrial biotechnology, encompassing primarily the contained use of GMOs in production. The term white biotechnology aimed at signalling the white coats of the laboratory and cleaner solutions for industry – referred to as the gateway to a more sustainable future – as in the headline of EuropaBio's pamphlet.

The term has thus been used to potentially ease the way for the use of biotechnology in industrial applications ensuring political acceptance, as argued amongst others by the producer of industrial enzymes, DSM, (DSM, 2004).

With the OECD report from 2001 on Application of Biotechnology to Industrial Sustainability, the environmental perspectives of new biotechnology has very much been associated with the 'cleaning' of industrial processes and products. The use of renewable resources in production, by substituting for example fossil fuel based materials with agricultural crops and crop residues are included in these perspectives (see ao. www.bio.org).

The use of new biotechnology for remediation, as dealt with in ao. OECD, 1994, and mentioned very early on in biotechnology development, falls between these three 'generations'. A number of explanations can be suggested for this. There are risk concerns due to deliberate release of GMOs into the environment. However, both researchers, industry and regulators mention that this "inter generation" biotechnology for remediation may play a role in future pollution control..

4.1.1 Environmental perspectives and concerns

Although low on the list of R&D resource allocations, the potential positive environmental perspectives of new biotechnology have been pointed to by researchers from very early on: Biotechnological treatment of waste before or after it ends up in the environment; biotechnology for cleaner industrial processes and products, and biotechnology for detection and monitoring.

According to several stake-holders (see ao.Europabio, 2003, OECD 1998, d Danish Ministry of Environment, 1985) focus in the beginning was on biotechnology as an end of pipe solution, either to clean air or water before leaving the production plant or to clean already polluted air, water or soil. Biotechnology for detection and monitoring was partly part of this.

In Denmark, the positive environmental perspectives of new biotechnology have at least from the 1980s been on the agenda, in broader debates on new biotechnology, in arguments for specific new biotechnology product developments (Kjærgaard, 1986), and in policy considerations (Danish Ministry of the Environment, 1985)

Later on biotechnology was identified as offering alternative production processes, reducing the use of unwanted chemicals, reducing the use of resources and/or making the use of alternative resources possible. OEDC (OECD, 2001) has identified and presented a selection of industrial examples of this, and also EuropeaBio (EuropaBio 2003) has presented various examples on how ‘white biotechnology’ may lead to environmentally sounder production processes.

Both the public and scientific debate focused more on the new biotechnology’s potential negative environmental consequences than on the potential positive environmental gains.

From the mid 1970s environmental concerns were an issue at scientific conferences and in science magazines and journals, and potential introductions of regulatory measures were discussed. Genetic researchers and industry were pressed by critical researchers and environmental NGOs, who questioned if the environmental consequences had been sufficiently considered.

As a consequence of this debate, the question about regulation was brought to discussion. In the 1980s, especially concerns related to the industrial use were met by regulatory measures, responding to the developments within this sector, especially in the pharmaceutical industry.

Later discussions focussed on the deliberate release, especially of plants. Again both critical scientists and environmental NGOs initiated these debates. Agricultural and other organisations, have increasingly participated in these debates on the side of the environmentally concerned. Concerns have addressed both the consequences of contamination of crops with GMOs, the development of herbicide resistance (to the same herbicide) in a number of crops potentially making the crops weeds, and the costs related to any groundwater contamination.

4.2 The desk study

The desk study on biotechnology and environmental perspectives is meant to give the background for the status of how biotechnology and its environmental perspectives have been conceived, and for scoping the Danish study on biotechnology and the environment. The survey of the Danish activities is given in the following and a number of studies are discussed.

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Focus has been on the environmental aspects. The biotechnologies and their applications discussed in the following have been selected because of formulated environmental perspectives, primarily their potential positive perspectives with regard to the reduction of environmental and health consequences, and with regard to the reduction of resource utilisation.

Attempts to survey any negative environmental and health consequences are also made. As will be returned to later, these consequences have been more difficult to identify within white biotechnology. The more radical and extensive uses of biotechnology within pharmaceuticals and agriculture, with far reaching environmental, health and ethical consequences have not been part of this foresight. The strong economic and industrial interests of the plant, food, and pharmaceutical industries as well as the strong interests of the medical area, and the NGO's focus on release and human ethics, are not as distinct within industrial biotechnology, and the negative environmental consequences thus not so much an issue in policy or debate.

Though positive environmental perspectives have been mentioned all along, they have especially become prevalent in the broader political debate from the 1990s. As it appears from the following, the positive contributions of new biotechnology to the environment has been on political agenda longer, but for the first many years of new biotechnology development, the drivers and the political motivation for the focus on biotechnology were the productivity gains it offered and the possibility for developing new product qualities. This was the case within pharmaceuticals, foods and plants.

In foresights on new biotechnology and reports on the environmental perspectives, a number of applications of new biotechnology in industrial production were launched, in addition to biotechnology for remediation. As a focus in this report five main fields of biotechnology were chosen, namely:
1) the development of new industrial processes, mainly enzymes,
2) fermentation efficiency (including fermentation efficiency in enzyme production)
3) the development of processes for producing bioplastics and degradable biopolymers,
4) bio-ethanol, and
5) the development of micro-organisms for treatment and remediation.

The two large areas of biotechnology development, medicine and health, and genetically modified plants and new biotechnology based foods, have been included in other foresight surveys, and have therefore not been included here, though the economic productivity gains which have been obtained, may also have an environmental, resource saving side to them. As will be demonstrated, this focus means leaving out a very substantial part of new biotechnology developments.

4.2.1 Sources for the desk study

For the account of the development of biotechnology development and the expectations regarding the environmental consequences, a number of Danish and OECD reports will be drawn upon, together with EuropaBio documents and industry statements. It is demonstrated how the environmental perspectives have always been part of the agenda, but also how the development until the 1990s has been rather anonymous, in rethorics as well as in policy and concrete activities. Table 4.1 gives an overview of the studies presented and discussed.

Table 4.1, overview of sources for the desk study

Year	Source
1985	The Ministry of Environment , The Genetic Engineering Group of the Danish Technological Council
1994	OECD
1998	OECD
2000	IDA (The Danish Association of Engineers), 2001, Bioteknologi – mellem drøm og dilemma (Biotechnology – between dream and dilemma)
2001	OECD, 2001, The Application of Biotechnology to Industrial Sustainability- New Biotech Tools for a Cleaner Environment;
2003	EuropaBio, April 2003, White Biotechnology: Gateway to a More Sustainable Future; and
2004	Royal Belgian Academy Council of Applied Science, January 2004, Industrial Biotechnology and Sustainable Chemistry.
2004	The American, Biotechnology Industry Organisation, 2004, New Biotech Tools for a Cleaner Environment

4.2.1.1 The Ministry of Environment , The Genetic Engineering Group of the Danish Technological Council

In 1985, the Ministry of Environment edited a booklet on the environmental perspectives in new biotechnology. They 'wanted a survey of wether genetic engineering could be applied in industry or other business with positive effect on the environment' (authors translation). The report points to the general advantages of new biotechnology as:

- contribution to the improvement of the efficiency of the organisms in existing biotechnology production
- substitution of chemical industry, which is a heavy polluter

The report is divided into three parts:

- genetic engineering in general
- the application of genetic engineering in Denmark
- examples of application possibilities, and comparison of aspects of genetic engineering versus traditional use

Application of genetic engineering in Denmark is referred to be within

a) Chemical production etc. 1) enzymes and 2) pharmaceuticals
b) reprocessing of vegetable raw material 1) in breweries
c) reprocessing of animal raw material 1) in dairies 2) in the food industry
d) agriculture
e) hospitals

Areas where genetic engineering is expected to be of future importance are identified as

a) processing of mineral oil
b) chemical production etc.
c) reprocessing of vegetable and animal material
d) processing of waste
e) husbandry, agriculture and forestry
f) wild life population

In the report, a comparison of the application potentials is made within the examples of:

- enzyme production
- production of animal and vegetable oils
- waste treatment, water sewage and waste water from chemical industry
- vitamin production, vitamin c og vitamin B2
- herbicides (alternative products) such as a) production af herbicides and b) introduction of resistance into the plants
- vaccines
- plant modification, for example modification of barley

The way these environmental potentials will be realized are categorized as:

- making industrial processes more effective
- substituting the methods for production existing agents and products with biotechnology production methods
- the construction of organisms to combat pollution, pests and weed
- production of food with a high nutritional content

The report concludes that:

- biotechnological processes in many cases are an advantage
- changes from chemical to biotechnological processes will lead to substantial changes in resource and raw material use
- genetic engineering may be used to renew and improve in food production
- genetic engineering may be used to sewage treatment and to combat of existing pollution
- nitrogen absorbing plants do not substantially solve the problem of the washing out from agricultural soil, but may bring down the need for nitrogenous fertilizer

4.2.2 Biotechnology - environmental focus in the late 1980s

Though the report from 1985 identified a number of ways in which new biotechnology would contribute positively to the environment, the potential positive environmental aspects were not a high profile issue in the 1980s and the beginning of the 1990s.

Herbicide resistant plants were not mentioned in the 1985 report as environmentally advantageous, but were promoted by seed- and chemical industry as having positive environmental consequences. However, the many controversies over the release of plants meant, that plant technology did not become regarded as environmental biotech, only as potentially having also positive environmental consequences.

Activities and environmental enthusiasm were therefore modest in the late 1980s and the beginning of the 1990s. And when the OECD decided to initiate activities in 1991, focus in these activities was on combating existing pollution, not on biotechnology as a more sustainable production technology or leading to more sustainable products.

Industry, primarily, argued the genetically modified herbicide tolerant plants as environmentally advantageous. The industry's driver for the development of the herbicide tolerant plants had, however, been one of efficiency or productivity. So together with the many environmental controversies with regard to diffusion of the GM plants, the disputed environmental advantages to be disadvantages, and the potential reduction in biodiversity and damage to flora and fauna, the herbicide tolerant plants were disputed as an environmental advantage.

The environmental perspectives from the use of genetically modified organisms for remediation and their application for ao. industrial enzyme production were acknowledged as potentials, but not a big issue. Regarding remediation, activities were modest, amongst other because of the release issue, whereas enzyme production progressed without big arm swinging regarding the environmental perspectives, but not with much scepticism towards it either.

4.2.2.1 The OECD, 1994

In 1991 (OECD, 1994) the OECD initiated activities with regard to the environmental perspectives within biotechnology. With their report from 1994 (OECD, 1994) they focussed on the role biotechnology might play in relation to already existing pollution with the report 'Biotechnology for a clean environment. Prevention, detection, remediation'.

It was amongst other meant to respond to 'the occasional misapprehension that the environmental implications of biotechnology are mainly a cause for concern´, and addressed the application of biotechnology to 'clean' after industrial productions.

The report refers to the relatively modest development of environmental biotechnology. It is stated that biotechnology for a clean environment has developed much slower than biotechnology in the medical and food sector. This slow development is explained with the science-push character of modern biotechnology in general, and suggests the following explanations:

- that environmental biotechnology 'often could not compete in glamour with medical and agricultural biotechnology'
- that environmental biotechnology 'does not have the same ''natural'' R&D constituency as medical and agricultural research sectors' – ' it is too vast a field, complex and ill-defined
- the 'greater difficulty of some underlying scientific questions' (multitude of interactions between plant and microbial species and the environment'

They categorize the number of ways in which biotechnology can prevent or reduce environmental damage as:

- added-value processes, which convert a waste stream into useful products
- end of pipe processes, in which the waste stream is purified to the point where the products can be released without harm into the environment

- development of new biomaterials, the manufacture of materials with reduced environmental impact;
- new biological processes, which generate less waste.

The report notes the increasing growth in environmental biotechnology, but refers to the uncertainties regarding the environmental and economic aspects as limiting diffusion. Increasing environmental regulation and support for environmental initiatives are referred to promote environmental technology; but it is also referred that application of biotechnology to environmental purposes, will take many years because there are many scientific, technological and economic black boxes.

It further refers to the lack of engineers with a biological or biotechnology background within the productions, where biotechnology could be used for environmental purposes, as contributing to the slow development of biotechnology for environmental purposes. Biotechnology is not regarded as a possibility, because engineers are not educated in the biological or biotechnology thinking.

However, despite the referred environmental uncertainties, which might limit biotechnology applications, the report also mentions that the high public acceptance of biotechnology for environmental purposes (stated in Eurobarometer 1991 and 1993) as potentially reducing uncertainty and contributing to the reduction of the development times needed.

The later increased focus on the contribution of biotechnology to the development of cleaner processes and products in the industry, has according to EFB, been a general tendency in industrial production following amongst other the Brundtland Report from 1987 and the Earth Summit in Rio de Janeiro in 1992.

Though the potentials for biotechnology to contribute to cleaner production, were referred to also earlier, e.g. in the small popular publication from the Danish Ministry of environment in 1985, where biotechnology is stated to:

- contribute to the improvement of the efficiency of the organisms in the existing biotechnological production
- change parts of the chemical industry that are very pollutant
- the focus on these perspectives remained low on the strategic or political agenda. Biotechnology developments in medicine, in the human genome project, in the pharmaceutical industry and in the herbicide tolerant plant development, dominated.

The increased focus on the environmental potentials of using biotechnology as a cleaner technology in industrial processes from the mid-1990s, is amongst other demonstrated with a number of publications from the OECD and others.

4.2.2.2 OECD, 1998

The report states the shift in paradigm which has taken place since the early 1990s. From the need to remove pollutants, to the possibilities for reshaping industrial processes and thus prevent pollution at the source.
But it is also stated that the concepts of cleaner industrial production is further ahead than the technical possibilities. And the report aims at pointing to the initiatives needed to close this gap and the bottlenecks which exist.
The report p. 7, identifies three main drivers for cleaner technology:

1) Economic competitiveness, with companies considering the advantages of clean products and processes in terms of market niches or cost advantages;
2) government policies, which enforce or encourage changes in manufacturing practices; and
3) public pressure, which takes on strategic importance as companies seek to establish environmental legitimacy'.

The report is referred to address politicians, industry and the public, who should be alerted to the potentials of new biotechnology, and the initiatives needed to realize these potentials (authors' formulation).

The report (in chapter 2) goes through examples of how biotechnology is used in six of the sectors, which contribute substantially to pollution in the OECD. Also their economic importance is evaluated.

The OECD distinguishes between biotechnology as:

- leading to new (end) products, such as e.g. biopharmaceuticals and seeds
- leading to new processes for producing known products (e.g. insulin)
- leading to improved final products or improved processes, e.g. Enzymes

The six sectors:

- Chemicals. The chapter reviews commodity chemicals, fine chemicals, enzymes, pharmaceuticals, refined petroleum and coal products, plastics and crop protection chemicals. The chemical sector is stated to be a major generator of materials, a major consumer of energy and non renewable resources and a major contributor to waste and pollution. Biotechnology is most widely used in fine chemicals. Biotechnology is stated to be able to reduce fossil carbon consumption and thus also global warming in various ways: improving industrial processes and energy efficiency and producing biomass-based materials and clean fuels.
- Pulp and paper sector. Biotechnology penetration is referred to as large in Europe
- Textiles and leather
- In food and feed: penetration of new biotechnology is referred to as greatest in the USA
- In mining bioleaching/minerals oxidation and in metals, bioremediation and recovery are mentioned as having economic potentials.
- The energy sector biotech is stated to be especially important in pollution control, via development of bio-diesel, bioethanol and biodesulphurisation, which will replace energy-intensive and polluting systems with systems that are more environmentally friendly.

In OECD 1998 chapter 3 the science and technological trends and potential for exploiting the environmental biotechnology potentials are described. It is referred that 'The possibilities for developing environmentally friendly products and processes and to clarify which areas of research require efforts, it is necessary to examine public demand, economic demand and scientific and technological feasibility' (OECD 1998 p. 63).

The report categorizes the number of ways in which biotechnology can prevent or reduce environmental damage as:

- added-value processes, which convert a waste stream into useful products
- end of pipe processes, in which the waste stream is purified to the point where the products can be released without harm into the environment
- development of new biomaterials, the manufacture of materials with reduced environmental impact;
- new biological processes, which generate less waste

It is stated that biotechnology is not clean per se, and it is mentioned that innovations in chemical industry within the existing technology paradigms, reduce its environmental impact as well. For example, the biotech and chemical processes may produce different environmental problems.

The report states that so far, limited experimental results and general statements are used to argue for biotechnology as contributing to environmentally sounder production. Further it is said that evaluation is however requested as well as methods for these evaluations and a number of methods for these evaluations are mentioned in OECD 1998 p. 87 and categorised in table 4.1 p. 88:

- Environmental Management Systems (EMS) (Focus on auditing management systems)
- Risk Assessment (RA) (the likelihood that environmental safety limits may be exceeded or that adverse effects may occur)
- Technology Assessment (TA)
- Environmental Impact Assessment (EIA)
- Material Flow Analysis (MFA)
- Life Cycle Analysis /LCA)

LCA is mentioned to be an important instrument for evaluations, only recently used for evaluating biotech. In addition to the general problem of weighting the different pollutions against each other, data and measuring problems are mentioned. The secrecy of many industrial LCAs also limits possibilities for evaluation and thus policy making.

As introduction to chapter five it is claimed that the preceding chapters demonstrated the potential of biotechnology to provide basis for more environmental production. And from there on, the chapter discuss the importance of public attitudes.

Numerous surveys are referred to, including the Eurobarometer surveys and some American and Canadian surveys. Though none of these, as noted in the chapter, address industrial biotechnology and bioremediation techniques, the importance of informing and educating the public is emphasised, and it is suggested to build on the public support for improving the environment.
It is stated that global environmental development and international commitments are very important for the development of cleaner industrial processes. Regulation and voluntary agreements are mentioned to increase the need for innovation, and policies that involve the public are referred to have the most far-reaching effects. Also consumer demand for cleaner products is referred to as putting pressure on manufacturers to meet this demand.

In a chapter on political recommendations, the recommendations to policy makers and industry are particular policies to act together to facilitate the penetration of biotechnology as an enabling technology: R&D policy, particularly building a bridge from basic research to implementation, ao. via demonstration projects.

Though the report identifies the two major drivers as regulatory policy and peoples' life styles, these are not addressed in the political recommendations.

4.2.3 Further development of the focus on processes and products

Also, The European Federation of Biotechnology, which presents themselves as the non-profit association of all national and cross-national Learned Societies, Universities, Institutes, Companies and Individuals interested in the promotion of Biotechnology throughout Europe and beyond, in a EU Commission supported article from 1999 refers to 'a pervading trend towards less harmful products and processes; away from "end of pipe treatment" of waste streams, indicating that end of pipe contributions had been dominant until then.

In the beginning of the 2000s, several reports appear in which focus increasingly is on biotechnology as contributing to environmental improvements: cleaner products and processes in industry, products that save resources or substitute resources in user industries, and products which reduce waste problems. Examples of these reports are:

- IDA (The Danish Association of Engineers), 2001, Bioteknologi – mellem drøm og dilemma (Biotechnology – between dream and dilemma)
- OECD, 2001, The Application of Biotechnology to Industrial Sustainability- New Biotech Tools for a Cleaner Environment;
- EuropaBio, April 2003, White Biotechnology: Gateway to a More Sustainable Future; and
- Royal Belgian Academy Council of Applied Science, January 2004, Industrial Biotechnology and Sustainable Chemistry.
- The American, Biotechnology Industry Organisation, 2004, New Biotech Tools for a Cleaner Environment

These reports focus on application of biotechnologies, and their contributions to reduce environmental load/strain on the environment, either by reducing resource use in production; by reducing resource use by using a biotechnology product; or by reducing waste. All reports give a number of examples where biotechnology reduces environmental strain.

4.2.3.1 IDA, 2000

IDA, 2000, reviews the Danish biotechnology development, and identifies environmental potentials, drivers and barriers for this development. The report, based upon amongst others OECD, 1998, identifies the potentials of industrial biotechnology as within:

- chemicals and pharmaceuticals, including bio-polymers
- paper, bio-bleaching, trans-genetic trees, reuse of paper masse and removal of by-products
- foods (including biological pest control)

- textiles and leather
- metals and minerals
- energy – improved regain of oil and hydrogen production

Additionally, the cleaning potentials of new biotechnology are stated to be within: earth/the ground, where a distinction is made between different ways of combating pollution:
a) already existing microorganisms in the ground which with minimal help can remove the pollution
b) bacteria which can be grafted on to the polluted ground and break down the unwanted substances
c) planting of plants which can take up or break down environmentally damaging substances
water – in sewage plants, in the ground water, in the sea and in lakes etc. In sewage plants, focus is referred to be on optimising at different levels: developing processes that generate less sludge, give more usable products for fertilisers and give more energy efficient cleaning
air, where 3 principles for cleaning is referred:
a) biofilter with a biofilm of microorganisms
b) a trickle bed bio reactor (to some extent similar principle as the bio filter)
c) bioscrubber reactor (a chamber for gas adsorption and a mud tank)

The report gives a thorough account of the technical possibilities which biotechnology offers to reduce resource use, to substitute chemical raw materials and to contribute to cleaning within a number of areas.
The report on the one hand identifies technical possibilities for environmental applications of new biotechnology, on the other hand identify the companies and institutions in which new biotechnology development take place.

The report thus opens up for discussions of the structural conditions for the development of biotechnology for environmental purposes, and opens for identifying areas which may be further stimulated by research grants etc.
The report also mentions the strong positive impact that environmental regulation may have on biotechnology development; but these regulations are primarily found in industries in which biotechnology is applied, not in the biotech industry.

4.2.3.2 OECD, 2001

OECD, 2001, distinguishes between the environmental perspectives of new biotechnology as:

- the replacement of fossil fuels raw materials by renewable (biomass) raw materials
- the replacement of a conventional, non-biological process by one based on biological systems, such as whole cells or enzymes, used as reagents or catalysts

A substantial part of the report, and a part whose contribution has been cited extensively for its collection of 21 examples of industrial biotechnology. The cases compare the environmental impact of using traditional/existing technology with new biotechnology, and find that new biotechnology in these cases contribute to the reduction of the measured negative environmental impact.
The descriptions of the 21 examples comprise:

- Manufacture of Riboflavin (vitamin B_2)

- Production of 7-Amino-cephalosporanic Acid
- Biotechnological Production of the Antibiotic Cephalexin
- Bioprocesses for the manufacture of Amino Acids
- Manufacutre of S-Chloropropionic Acid
- Enzymatic production of Acrylamide
- Enzymatic Syntheses of Acrylic Acid
- Enzymatic-Catalysed Synthesis of Polyesters
- Polymers from renewable Resources
- A Vegetable Oil Degumming Enzyme
- Water Recovery in a Vegetable-processing Company
- Removal of Bleach Residues in Textile Finishing
- Enzymatic Pulp Bleaching Process
- Use of Xylinase as a Pulp Brightener
- A life Cycle Assessment of Enzyme Bleaching of Wood Pulp
- On-site production of Xylinase
- A Gypsum-free Zink Refinery
- Copper Bioleaching Technology
- Renewable Fuels – Ethanol from Biomass
- The Application of LCA Software to Bioethanol Fuel
- Use of Enzymes in Oil-well Completion

The examples are taken from Germany, the Netherlands, the United Kingdom, Austria, South Africa, the United States and Canada, and cover the pharmaceutical, the fine chemicals, the bulk chemicals, the food and feed, the textiles, the pulp and paper, the minerals and the energy sectors (OECD 2001, table 1 p. 12).

4.2.3.3 Europa Bio, 2003

Europa Bio, April 2003's, 'White Biotechnology: Gateway to a More Sustainable Future', gives a 'brief summary of a study, conducted by six innovative companies who are amongst the pioneers of white biotechnology', to demonstrate the contributions of white technology.
From this selection of case studies, the environmental impact factors of biotechnology and traditional processes are identified as:

- energy use
- raw materials
- emissions
- land use
- toxicology

The six examples have repetitions from the OECD study, and include:

- vitamin B_2,
- antibiotic Cephalexin,

- Scouring enzyme,
- NatureWorks[tm],
- Sorona[r], and
- Ethylene from biomass

From the examples they make estimates for the potentials for a more sustainable society.

More examples are found on their home page, including enzymes produced by genetic engineering for detergents, for cheese production, for sweeteners, for breakdown of pectin in cotton, for industrial stonewashing (without stones), and for bread's extended shelf life (www.europabio.org, accessed 22/4-2004).

4.2.3.4 The Royal Belgian Academy, 2004

The report from the Royal Belgian Academy Council of Applied Sciences from January 2004, draw on the examples of:

- food additives and food supplements
- bio-pesticides
- bio-colorants
- solvents
- plastics or bioplastics
- vitamins
- fine chemicals and pharmaceuticals

and within biofuels:

- bio-ethanol
- bio-diesel
- biogas

The descriptions of the applications are less company specific than those of OECD and EuropaBio, and to a larger extent relate to general environmental problems. The recommendations – to industry as well as to public policy – are therefore also to generally strengthen biotechnology development – though it is recommended that this is 'done in a structured, strategic and goal oriented manner.

4.2.3.5 The American Biotechnology Industry Association, 2004

The American Biotechnology Industry Organisation, 2004, explicitly builds on OECD, 2001, and expands the findings from the OECD, 2001, primarily in relation to the US industrial sector. The case studies encompass:

- Pulp and Paper Production and Bleaching
- Textile Finishing
- Plastic and Chemical Production
- Fuels Production
- Pharmaceutical and Vitamin Production

Additional Examples of Biotechnology in Action, including energy, mining, textile manufacturing and food processing.

In the summary for policy makers, the key findings are referred to as: Industrial biotechnology offers the private sector remarkable new tools for pollution prevention which have not been widely available before now.

These new tools not only prevent pollution but can also significantly cut energy demand, natural resource consumption, and production costs while creating high-quality intermediates or consumer products.

Accelerated uptake of new industrial biotechnology processes could lead to further pollution prevention, waste reduction, and energy cost savings in related services such as waste disposal or energy production.

Public policies and regulations do not provide adequate incentives for technological innovations, such as biotechnology-based pollution prevention and energy savings.

The industrial biotechnology processes used in this analysis involve cutting-edge technologies. More research and development must be undertaken to increase the utility and efficiency of these biotechnology processes across a broad range of industrial applications. The policy considerations are rather general and not very binding, and limit themselves to - considerations.

4.3 Danish activities and expectations to biotechnology development and its environmental perspectives

As referred to in the previous paragraph, the Danish Ministry of Environment already in 1985 identified applications of new biotechnology that might imply environmental benefits. At the same time the potential negative consequences were discussed within a number of fora, with focus on regulation needs. The potential positive environmental arguments for new biotechnology did not disappear completely from the agenda, but the drivers for the biotechnology development were others. Pharmaceutical industrial research and public medical research dominated both the public and private research and development.

The plant and seed industry's response to the environmental concerns for pollen diffusion, harmful effects on insects of pest resistance, and concerns over increased herbicide spraying as the consequence of introducing gm-plants, was to argue for environmental benefits of the plants, stemming from potential reductions in herbicide use and increased biodiversity as a consequence of later sprayings. Based on the argumentation research agendas continued to focus on herbicide resistance.

The environmental benefits of industrial use of a.o. enzymes from genetically engineered micro-organisms, were, to some extent, referred to, but these were not used as a 'sales argument' by industry, neither to customers, nor to policy makers, as far as we found. The production of enzymes, produced on the basis of genetically engineered organisms, became increasingly efficient, and was consequently welcomed in a number of industrial processes, resulting in increased productivity by reducing the use of resources.

However, the tendency of not promoting environmental benefits changed. Enzymes increasingly became envisaged as applicable within a larger number of areas, enabling the use of amongst other waste materials, reducing scarce resources or substituting unwanted chemical agents. Consequently, industry as well as public institutions became more promotive of new biotechnology as a more environmentally sustainable technology.

The mentioned OECD reports contributed to that; parts of the biotech industry organisations hired consultants to analyse the potential environmental benefits (or they carried out assessments on their own); a number of institutions and companies worked with substitution of scarce resources by using biomass; and professional as well as Government institutions, such as the Danish EPA with this report, again considered ways in which they might introduce policies that would lead to the use of biotechnology to improve environment in areas where existing structures (price structures, company structures, regulation etc.) would inhibit the use of new biotechnology.

Also the Engineering Association's report from 1999, 'Biotechnology - Between dream and dilemma' was in the same line and aimed at identifying the role that engineers might play to support broader applications of ingenious (in Danish 'snilde') and cleaner biotechnologies (The aim is more diverse in the report, and the aim here is the authors' interpretation of it.)

The Danish development with increased focus on biotech as contribution to sustainable biotechnology, has thus been part of the wave of revived focus on the environmental perspectives of new biotechnology. And with more than 50% of the world enzyme production, Denmark, or especially Novozymes A/S has been central for contributing to this wave.

4.3.1 Danish biotechnology activities

The mapping of the Danish biotechnology development described in this chapter, aims at showing the role of the industrial biotechnology development in the overall biotech development and to give some impression of the environmental biotechnology activities.

A number of sources have been used for this mapping, both quantitative sources and more descriptive reports. Reports and surveys and a variety of company material and institutional material have been used to identify specific companies and research environments for subsequent interviews.

A limited number of interviews were made for the purpose of identifying ongoing industrial and public research activities, the conditions for these activities, and the potential environmental aspects and developments..

Primarily research and development departments have been approached with the inquiry for an interview, with one or more persons, together or separately. With the limited resources for the survey on the one hand, and the limited number of institutions on the other, it has been assumed that this way of mapping perspectives, networks, institutional conditions, etc. has enabled a nuanced image of the industrial biotechnology activities and their environmental perspectives. Interviewees have been asked about their development activities and the role of universities and research institutions, suppliers, customers, and regulation for this development.

Regarding especially the potential negative environmental consequences of new biotechnology, NGOs and the Ministry's 'Agricultural and biotechnology office' have been approached, the latter being responsible for the regulation of the contained use of GMOs and for the preparation of notes for the Parliamentary decisions on deliberate release. Only one NGO has been interviewed.

4.3.1.1 New biotechnology R&D in Denmark

Biotechnology R&D has developed rapidly in Denmark, in public research as well as in industry. The biotechnology development, measured as biotechnology R&D, has increased and operational costs in 2001 were five times the size of what they were in 1987. Also the distribution between private and public R&D has shifted, with an increasing share of research carried out in the private sector, see table 4.2.

Table 4.2.
Operational costs in biotechnology R&D in Denmark 1987, 1995 and 2001 mio. DKK.

	1987	1995	2001
Operational costs in R&D, total	725	2522	4032
Operational costs, industry	438	1675	3149
Operational costs, public institutions	287	847	883

Source: Analyseinstitut for Forskning, Forskningsministeriet, Forskningssekretariatet Undervisningsministeriet and Forsknings- og teknologiministeriet, selected years.

Medicine and health, and genetically modified plants and new biotechnology based foods also in Denmark have constituted the majority of R&D. These areas have been included in foresight surveys initiated by the Ministry of Science, Technology and Innovation and the Ministry of Environment, with the latter plant foresight explicitly focussing on the environmental consequences.

The focus in this project is on industrial biotechnology and new biotechnology as a remediation technology, and it therefore only covers a rather limited, but maybe in the future increasing part, of new biotechnology.

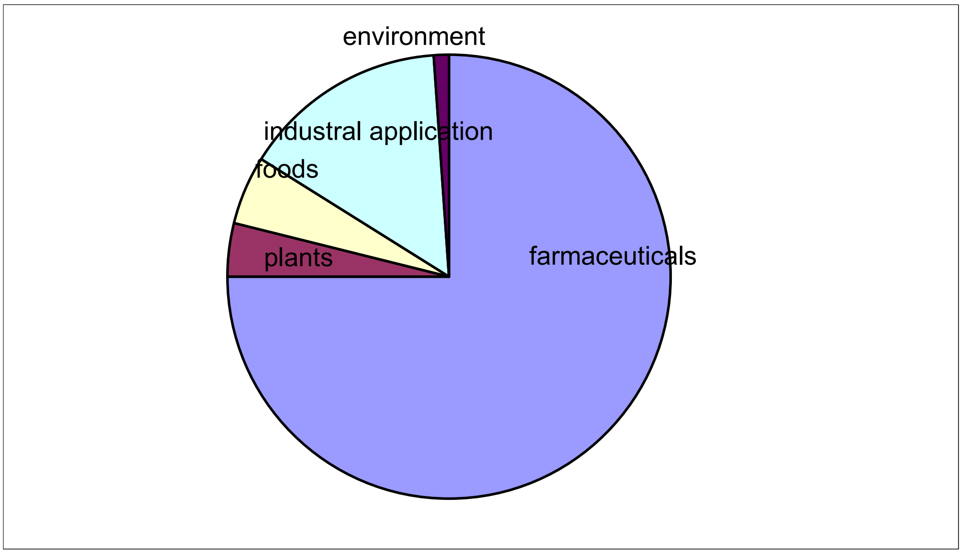


Figure 4.1. Estimate of the distribution of new biotechnology research.

Note: Authors' very rough estimate, on the basis of R&D statistic, annual reports, interviews and more. Analyseinstitut for Forskning 2001, estimates 90% of research to be within pharmaceuticals.

The environmental aspects have been the focus, and the technologies discussed in the following have been selected because of their perceived positive environmental perspectives, regarding the reduction of environmental and health consequences, and with regard to the reduction of resource utilisation.

The distribution of the biotechnology research and development between industrial areas are rough estimates. The Danish Centre for Studies in Research and Research Policy is under obligation of secrecy, and is therefore only allowed to publish the medical and the pharmaceutical research and development. They estimate (Analyseinstitut for Forskning, 2001) that 90% of the private biotechnology research and development is carried out within pharmaceutical products and new medical treatments. Hansen, 1996, made a loose estimate of 50% of the private biotechnology research and development to be within pharmaceuticals and medicine, and to be increasing. The increase to 75% is thus also very rough.

Also the other estimates are very uncertain, due both to the uncertainties in delimiting the definition of new biotechnology, the applications of new biotechnology and the lack of both public statistics and statistics in general. But it is generally agreed that a large share of new biotechnology research and development is carried out within medicine and pharmaceuticals. The uncertainties, however, mean that more substantial conclusions cannot be made.

Enzyme research and development has increased (estimated, with the use of R&D percentages from 2001 -2003 used on sales figures from the 1990s), while new biotechnology based food research has been relatively modest throughout the period. Consumer concerns have been referred to both by industry and by policy consultants as contributing to the low R&D activities (see for example IDA, 2000, Kjeldahl, 2004, Mortensen, 2004).

Public research is even more difficult to categorise, since it is less application oriented. Much of the basic research is applicable in a variety of areas, though it is not always applied in the many areas. Mostly medical and pharmaceutical R&D and production are referred to as being the actual users of the R&D, though often not formulated potentials may be found in other areas (Nielsen, interview 2004).

An increasing share of the R&D resources was by several interviewees mentioned to be allocated to more application oriented research. The large share of resources going to application oriented institutions such as the Technical University of Denmark, may point in the same direction, as well as private donations from a.o. Novozymes A/S to technical research.
Plant research has been mentioned to have been reduced in the public sector as well as in the private sector. Private research to some extent was driver of public research – supporting public research as well as contributing by being on the research front in specific areas. Some of the public research was in addition spurred by the need for public knowledge for risk and environmental assessments.

4.3.1.2 Public biotechnology R&D in Denmark

As many other countries, Denmark has experienced a marked increase in biotechnology research and development. The number of person years within new biotechnology has tripled within a decade, an increase to which a number of public R&D programmes contributed.

Table 4.3.
Public biotechnology R&D in Denmark.

	1985	1987	1989	1991	1993	1995	1999	2000	2001	2002
Number of institutes						134	157	97	114	113
R&D manpower, person-years	440	746	851	1102	1207	1451	1706	1010	1358	1297
Operational expenditure, Mill. DKK		287	367	519	609	847	914	704	883	870

Source: Analyseinstitut for Forskning, Forskningsministeriet, Forskningssekretariatet, Undervisningsministeriet and Forsknings- og teknologiministeriet, selected years.

New biotechnology and the public R&D programmes within new biotechnology have been promoted with reference to the Danish experience within biological production. This background has been argued to form the basis for exploiting the new biotechnologies and contribute to growth.
The localisation of the public R&D is concentrated around Copenhagen, but with important biotechnology research environments also in Århus, Aalborg and Odense universities. At Technical University of Denmark, DTU, a substantial part of the R&D directed towards the use of biotechnology in industrial processes is located; research in the cleaning technologies are located at DTU and at Aalborg university, and biotechnology processes for the production of or for use in the production of alternative fuels or materials are found at Risoe, DTU and at Odense universities.

Estimates point to medicine and pharmaceuticals as the major area, followed by research and development of which the eventual application will be in industry, and to plants.

The new biotechnology plant research has been referred by several to have decreased in the recent 5 years, with also decreasing private grants for public research. But figures are not very transparent to say the least.

For food research, a number of large R&D grants have been given to R&D institutes addressing applications in food industry and sustainable processes in various industries. And biotech food related research may be increasing, though again transparency is not characterising the area.
R&D institutes within remediation, base their research on new biotechnology R&D. But application potentials are referred to very cautiously.

4.3.1.3 Private biotechnology R&D in Denmark

The industrial biotechnology development in Denmark has, as mentioned and as in many other countries, been dominated by the development within medicine and pharmaceuticals, and to some extent within plants.
However, increasingly, R&D is found within industrial biotechnology, especially the production and use of enzymes, following substantial improvements in their production, and an increasing acknowledgement of the possibility for resource savings in application.

The number of companies with biotechnology research and development has generally been increasing from 1987 to 2001. Also the number of researchers has increased. The missing figures are not publicly available for discretionary reasons, or are estimated by the Analyseinstitut for Forskning to be too uncertain for publication (personal communication, 2004).

Table 4.4.
Development in private biotechnology R&D, 1987-2001.

		1987	1989	1991	1993	1995	1998	2001
Industry	Companies	27	37	28	28	28		
Other	Companies	12	8	19	13	19		
Institutes	Companies	4	5	8	8	8		
Total	Companies	43	50	55	49	55	74	72
R&D, current expenditure	mill. DKK	438	621	1022	1289	1675		3149
R&D manpower	person-years	1122	1470	2467	3115	3130		

Source: Analyseinstitut for forskning, Forskningsministeriet, Forskningssekretariatet, Undervisningsministeriet, Undervisningsministeriet and Forsknings- og teknologiministeriet, selected years.

The size of the R&D activities are unevenly distributed, with a few large companies estimated to have the major share of the activities.
The pharmaceutical biotechnology companies have been dominated by Novo Nordisk A/S, though a number of other pharmaceutical companies have important activities within new biotechnology as well. These have different backgrounds, amongst other being:

- spin-offs from large pharmaceutical companies, with activities outside their original company's core business
- spin-offs, that supply the original company
- new companies supplying companies and industries
- new companies developing into new pharmaceutical companies
- spin-offs from universities, which commercialise the university research

The private biotech plant research in Denmark was through the 1980s dominated by Danisco A/S. GM herbicide resistant sugar beets was the dominant area of research. Research activities were found within other crops as well as traits.

In the 1990s also the smaller seed firm, DLF-Trifolium A/S in cooperation with Danisco, has carried out research within genetically modified plants, fodder beets as well as other, among them energy crops. Several of the agricultural R&D institutions have also carried out biotech research, alone as well as in cooperation with DLF-Trifolium A/S, Danisco and Monsanto.
In food industry, in which R&D in general constitutes a small share of revenues, most of the science based research and development take place in a few large companies and very few smaller R&D companies.
Novozymes A/S dominates, in Denmark and in the world, within R&D in industrial enzymes. And within private R&D of new biotech methods for remediation, the Novozymes A/S owned American companies have a prevalent role.

The new biotechnology research in private companies is primarily located around Copenhagen, with an estimated larger concentration of private R&D of private R&D, than of the public R&D.

All the above mentioned companies' R&D, is located within 25 km of Copenhagen, with the exception of some parts of plant and food research.
The application of new biotechnology products, especially the application of enzymes, will however be much less regionally concentrated. The localisation of the applying industry will therefore be important to identify potential regional environmental consequences.

4.4 Selected biotechnology areas of environmental interest

Regarding the environmental perspectives within new biotechnology, the following areas of biotechnology application have been selected, on the background of the literature survey and the Danish activities:

- enzyme production and application
- fermentation efficiency,
- bio-polymers,
- bio-ethanol,
- biological base-chemicals, and
- bio-remediation
-

4.4.1 Enzyme production and application

As referred to above, enzyme technology is by far the largest field of industrial- or 'white' biotechnology, and is the major area of white biotechnology in Denmark, with Novozymes, Danisco A/S, Danisco-Genencor and Chr. Hansen A/S as large players in the field of enzymes and within their specialties.

The field of enzyme technology is referred to have been developed from pharmaceutical research and production, a strong agricultural base (in Denmark) and from thorough experiences with agricultural research and production. Large public as well as private investments in biotechnology R&D contributed to the biotechnology development from which the enzyme industry developed. The research and development budgets are relatively large, 12.8% of turnover in Danish Novozymes A/S in 2003 (Lhepner, 2004), less in the other Danish companies, though a breakdown on biotechnology is not possible.

Private industry is a prime driver of enzyme development, with public research supporting this development. The dominant players in the enzyme business have market shares of: Novozymes A/S 46%, Genencor 20% (now owned by Danisco A/S) and DSM 7% (Lhepner, 2004). (Novozymes A/S cooperates with the Dutch DSM). According to Lhepner, 2004, increasing fermentation capacity is installed (or achieved by fermentation efficiency increase) by the major players all over the world.

Advances in biotechnology enabled commercial enzyme production, and as the technology developed, an increasing number of enzymes have become commercially available. Production efficiencies still undergo rapid improvements, rendering enzymes more cost-effective and thus more competitive. Thereby an increasing number of applications fields for the enzymes are developed.

Another driver for increasing development and use of enzymes has been stated by industry to be driven be industrial and societal developments, towards greening and resource restrictions. Industrial customers and industrial end-users, are increasingly demanding 'greener' and energy saving products and processes, either to save on scarce/increasingly expensive resources or to comply with environmental regulation.

Collaboration with customers is therefore by Novozymes A/S regarded as very important for identifying areas where enzymes can contribute, and they have a number of internal activities aiming at identifying potential areas/industries of enzyme application. Both Novozymes A/S and Danisco A/S collaborate with large industrial customers, but not with the final consumers. Assumed demands and wishes of final consumers are considered more indirectly, either via the business customers or via Novozymes A/S'/ Danisco A/S' assumptions and assessments.

Collaboration with smaller companies is limited because of scale advantages or maybe scale necessities. Learning and investments are referred to limit the implementation in smaller companies by amongst other Novozymes A/S (Jensen, interview 2004), and the point made by ao. OECD, 2001 is similar, stating that not trivial shifts from chemical to biotechnology production, may require new competences and investments and thus be prohibitive.

R&D collaborations and specific demands to university environments were not mentioned explicitly as being driver of or prerequisite for green innovation. But though focus in the interviews were not on the needs for development of the public research (as has been the case in earlier surveys, see for example Hansen et al., 1991), all companies cooperated with Danish as well as other universities. However, collaboration was not referred to as paramount for the green aspects of development.

Industries, in which the enzymes from Novozymes A/S and others are used as catalysts for reducing resource use or for substituting resources, are amongst other:

- detergents
- the textile industry,
- pulp and paper industry,
- food and drink industries,
- animal feed industry and, as mentioned later,
- ethanol production.

Detergents have been known as an area of applications of enzymes since the 1950s, an area which has increased immensely in the last 20 years and still increases. The use of enzymes together with developments in detergents, reduced washing temperatures to 30-40 degrees, temperatures which are expected to be reduced even further. Scarcity of water and increasing oil and water prices are expected to further the development. Detergent enzymes, produced to a few customers, are still the biggest market for enzymes, for Novozymes A/S and in general. The production accounts for about 30-40% of Novozymes' revenues (Jensen, E.B., interview 2004), and the share of detergent enzyme research is approximately 30%.

The use of enzymes in textile industry, has amongst other addressed 'stonewashing' . A cellulase enzyme has been developed to replace abrasive pumice (volcanic) stones (EuropaBio, May 2002). Instead of getting the worn look of jeans by adding stones to the washing (followed by several rinsings), enzymes are added instead. The environmental advantages stated (EuropaBio, May 2002) are:

- a gentler treatment, and thus less wear on the garment and longer lifetime

- reduction in the amount of water for rinsing
- reduced wear on the machines (the stones wear on the machines)
- time reduction(– not necessarily an environmental advantage)

The use of enzymes breaking down pectin and other impurities in cotton, has been another application of enzymes in textile production. Compared to the most widely used alternatively process, the use of enzymes halve the use of rinsing water and lower the temperature from 95 to 55 degrees. Further, the milder process is stated to increase yield. And lastly, fewer chemicals are released into the environment. (EuropaBio, May 2002).

The pulp and paper industry has used amongst other chlorine to the bleaching of paper. The use of enzymes in the bleaching process has, according to Novozymes A/S, reduced the chlorine use with 30%, contributing also to reduced release of chlorine with constant production. (The constant use has not been the case, however.) Work health and environmental focus on reducing toxic chemicals were strongly contributing to the change of process.

The leather industry is also increasingly applying enzymes in the tanning process. In Denmark enzymes from animal pancreases have since 1908 been used in tanning processes, but with genetic engineering, enzymes can be developed to be used for several individual processes in the tanning (IDA, 2000). The environmental advantages are stated as both the reduction in chemical use, increased recirculation of rinsing water and better quality of the leather.

In animal feed industry, the development of phytase has contributed to a better exploitation of the phosphorus in animal feed and thus contributed to better bone building. The main driver for phytase application was however the contribution of phytase to the reduction of phosphorus from pigs and poultry in the ground water, in streams and lakes, and thus to the reduction of growth in algae and deoxygenation. The use of phytase increased with the introduction of strict Dutch regulation on phosphor release, a development which had had a very slow start. The use of phytase in fodder was further spurred by the ban on MBM use in fodder, following the BSE discussion and regulation.

Regarding *enzyme development within new areas,* Novozymes A/S looks for industries with large conversion of raw materials, the use of which can be more efficient with the use of enzymes. Potentials include efficiency gains, and the production of for example bio fuels or bio plastics, substituting fossil fuels for these applications. The costs are still high for these, but increasing fossil fuel costs may contribute to the cost advantages of alternatives.

Both Novozymes A/S and Danisco A/S refer to industrial and societal agendas as input to their consideration of research and development initiatives, in the short run as well as in the long run. Waste issues, water treatment issues, pesticide use and resource and fuel scarcity were mentioned by Novozymes A/S as general environmental problems, which technology development would have to address seriously in the coming years. More specifically, Hansen, interview 2004, also Danisco A/S refers to 'societal agendas' as influencing their development strategies – for example the use of emulgators as substitutes for phthalates in plastic packaging and the development of ingredients for low carb food production.

Though these societal developments were expected to further the development of enzyme development and application, very specific environmental benefits were mentioned not to be drivers of technological development, unless they were a result of actual regulation (Jensen, interview 2004 and Hansen, interview 2004), as in the mentioned cases. However, Hansen, interview 2004, mentioned the development of an alternative softener, as a potential substitute, in the case of a ban on phthalates.
With regard to *negative consequences* of enzyme development, very little or no research was referred to, as being carried out on potential negative risk and health effects, neither in the referred literature nor in industry, academia or public institutions.

To some extent this is not so surprising. Industry, industrial organisations and economically and growth oriented institutions have been responsible for most of the surveys conducted on the contribution of enzyme technology to environmental sustainability. But this is not the only explanation. Non-governmental organisations have not been pointing to negative consequences in general, either. The Danish environmental organisations have, since the 1990s focussed their concern and their critique of genetic engineering on the release of plants and micro-organisms into the environment. As Greenpeace campaigner Dan Belusa stated (Belusa, interview 2004), the regulatory framework for contained use in Denmark has to a large extent worked, and though there is still reason to criticise, when the systems ‘leak’, the environmental organisations focus their attention on release of plants and micro-organisms.

The regulatory authorities express some of the same considerations. Their main concern is release and coming releases – of plants, microorganisms and fish. Though there are still issues to assess with regard to enzyme production, the framework for doing it is supported. These potential environmental concerns may be allergic reactions to an increasing number of enzymes in the environment, in products, in air (from release) and in sludge.

Efforts to reduce allergic reactions have focussed on both ‘technical’ reductions e.g. coatings of the enzyme production, and by release control. However, the increased production and application of enzymes and new enzymes may however be followed to be able to react to unwanted or unforeseen consequences.

4.5 Environmental assessment of enzyme technology

Enzymes have various modes of operation in the process, in which they are applied. Typically, the enzymes catalyse a chemical reaction/degradation. The alternative process often implies the use of chemical auxiliaries, and using the enzymatic process, thus substitutes the use of other chemicals often being more hazardous to the environment. Moreover, the use of enzymes often increase raw material efficiency of the process and often reduces energy consumption as enzymatic process take place at lower temperatures.
Like for all other technologies, the environmental properties of enzyme technology are judged by a comparison with alternative technological means to do the same operations/provide the same services in industrial and household operations. Thus, an application of enzyme technology will imply an *induction* of certain environmental impacts from the production and use of enzymes as well as an *avoidance* of environmental impacts from the substitution of alternative operations.

Figure 4.2 illustrates the principle of induced and avoided operations. The figure, thus, shows the generalised system underlying any environmental assessment.

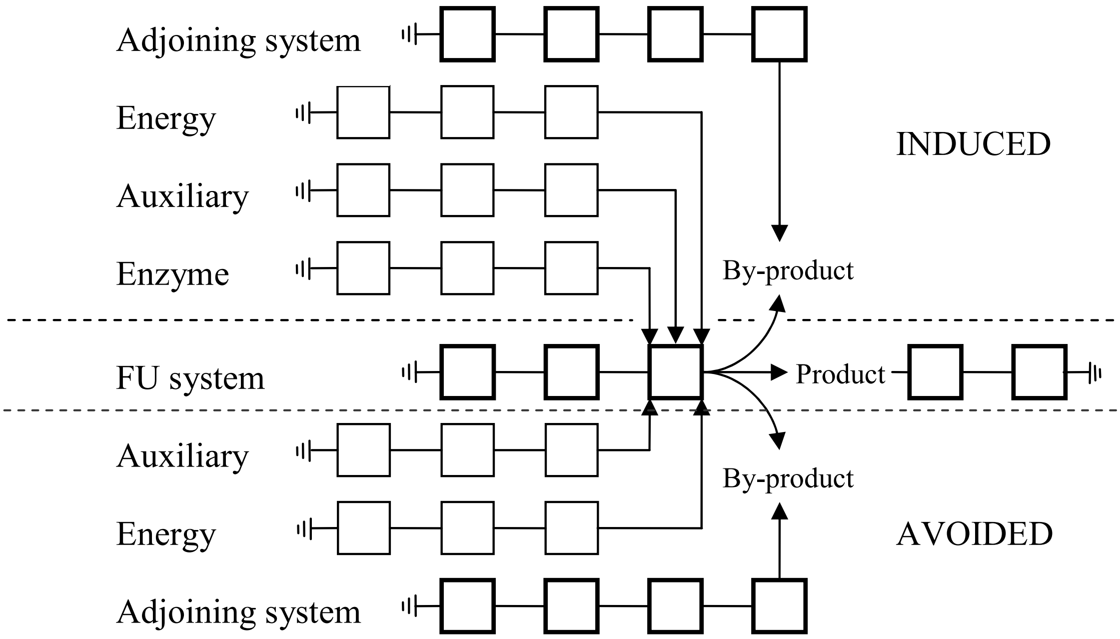


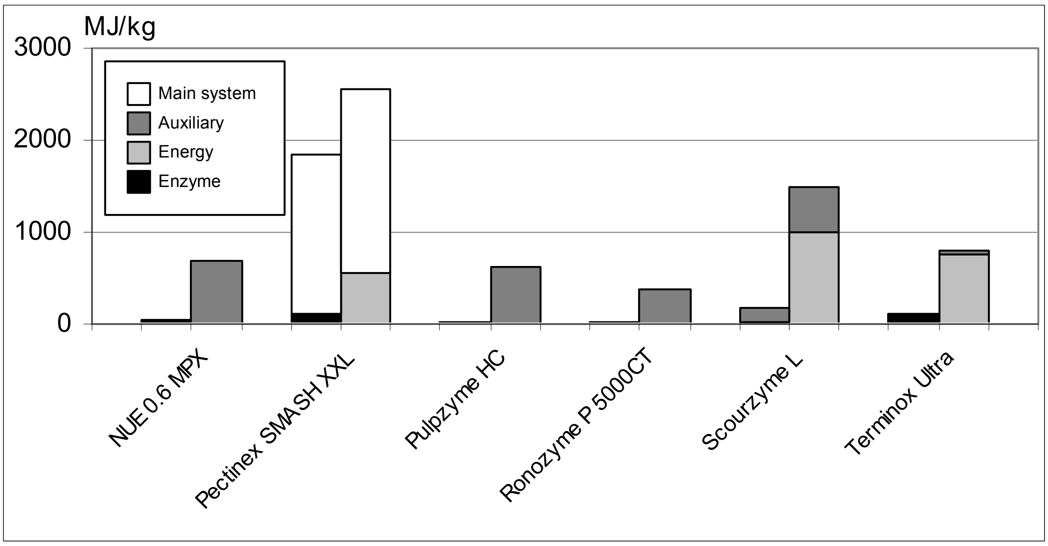
Figure 4.2.
The system affected when using an enzyme technology instead of its alternative.

Note: The production system, in which the enzyme is applied is called the FU ('functional unit') system, e.g. an apple juice production. This system is assessed from its cradle to its grave, and any alternative technology has to provide one and the same functional output of this system. 'Induced' operations are the systems for providing the enzyme and any supplementary auxiliaries and energy flows connected to the enzyme application. 'Avoided' operations are the flows of auxiliaries and energy avoided by substituting the alternative operation. Moreover, flows of raw materials (in the FU system) can be either induced or avoided when the enzyme alternative alters the raw material efficiency of the operation, and so can flows related to alternative provision of any by-products in case the production of these are altered by the application of enzyme technology.

A screening level assessment of 11 enzyme applications of large variety was conducted (Andersen & Kløverpris, 2004) assessing the holistic energy consequences of using enzyme technology instead of its alternatives. The assessment was based on a life cycle perspective, i.e. all changes when choosing the enzyme solution over its alternative were comprised, including raw material extraction, production, use and disposal within both the enzyme system and the alternative system. The 11 enzyme applications fall within the industries of:

- baking operations and bread conditioning
- textile wet treatment operations, e.g. bleaching, stone washing, scouring and more
- paper manufacturing, e.g. bleaching and deinking
- leather processing
- animal feed preparation, and
- food preparation

General results and conclusions on enzyme technology were extracted. Figure 4.3 shows the result on energy consequences of choosing enzyme solutions over their alternatives.



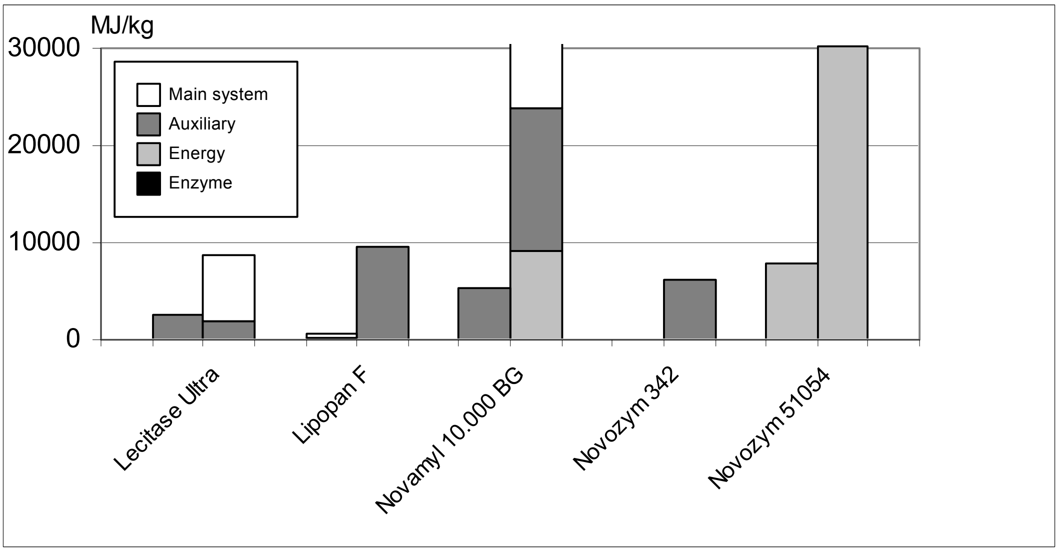


Figure 4.3
Overall energy consumption consequences of using an enzyme technology instead of its alternative for 11 enzyme applications.

Note: In each column pair, left column indicates induced- and right column avoided energy consumption. Source: Andersen and Kløverpris, 2004.

As evident from the figure, the enzyme alternative in all cases is the better alternative in terms of overall energy consumption. Moreover, enzymes are non-toxic, degradable substances of biological origin, and they often substitute chemical auxiliaries. Most often, therefore, chemical emissions and their potential hazard to the environment are lower from the enzyme alternative. On the two major environmental issues of energy and chemicals, thus, this screening strongly suggests that enzyme technology is highly favourable environmentally. Any potential environmental draw-backs of enzyme technology still remain to be documented. Issues like the use of land (enzyme fermentation requires agricultural products as substrates), any consequences of GMOs and any consequences in terms of allergic reactions by actors exposed to enzymes in the system still needs further quantification.

4.5.1 Fermentation efficiency

The rapid development of 'white biotechnology' involves a continuous search for more efficient organisms to provide the fermentation of the various products. This development comprises both the identification and selection of the most suitable host organisms and the genetic modification of these organisms. The development that has taken place over the last decade in this area is unprecedented with respect to the efficiency increases it has provided for the industrial processes based on fermentation. Increases in efficiency/yield of 5-10% are common, and this exceeds the parallel efficiency increases of any competing technologies by far. Genetic modification in this way provides a technology leap favouring the use of fermentation processes radically and implying a continued efficiency improvement of any fermentation operation, and thereby also an environmental efficiency increase. Moreover, the fermentation efficiency increase leads to increased cost-efficiency of enzyme production, and this strongly contributes to the continuous gain of new fields of enzyme application from conventional processes using chemical auxiliaries.

4.5.1.1 Environmental assessment of increased fermentation efficiency

The environmental aspects of the achieved increase in fermentation efficiency are quite unambiguous. The efficiency increase leads to resource savings on both raw materials, energy, water and other auxiliaries involved in the fermentation. Consequently, environmental impacts from the production of such resources are reduced accordingly. An increase of 5-10% per years corresponds to a halving of resource consumption and its related environmental impact over around 10-20 years provided that the efficiency increase stay at the same level as seen over the latest years (the realism of this has not been evaluated). The potential environmental trade-off is the use of more genetic modification that underlies the efficiency increase.

4.5.2 Bio-polymers

Bio-plastic production from organic (waste) material and plastic production with the help of enzymes has been an example in several of the conducted surveys on sustainable biotechnology in industry (a.o. OECD, 2001, Biotechnology Industry Organisation, and Royal Belgian Academy Council of Applied Science, 2004). Two environmental objectives, not necessarily interdependent, have been advanced: the release of plastic production from fossil fuels, and biodegradation of the plastics material to reduce waste, especially in food packaging and field covering plastic, referred to be used extensively in Asia and also in Southern Europe.

Commercial production is referred to take place in the US by Cargill Dow and in Japan by a.o. Mitsubishi Rayon. So far the activities in Denmark are referred to as having taken place in public institutions and in private consultancy, primarily with support from EU programmes' and primarily at the Risø National Laboratory and at Centre for Advanced Food Studies (LMC), The Royal Veterinary and Agricultural University.
At the Centre for Advanced Food Studies, focus is on the development of biopolymers for cheese packaging that will give the cheese extended shelf life. The environmental benefit is stated (http://www.flair-flow.com/industry-docs/ffe56602.html) as 'substituting fossil plastic materials by renewable biopolymers' which may at the same time 'improve the utilization of agricultural by-products.'

According to http://www.flair-flow.com/industry-docs/ffe56602.html, 'the new biopolymers may be based on proteins like casein, on carbohydrates like starch, cellulose or chitosan, on lipids, and also on polymers from surplus monomers produced in agriculture such as polylactate (PLA), and finally, on bacterial produced polymers from microorganisms grown on waste, like poly 3-hydroxy-butyrate (PHB).'

Risoe National Laboratory has had an ambition of building up R&D competences within bio-polymers, and to offer education of polymer students also in bio plastics. Projects have amongst other focussed on the development of biodegradable polymers for use in high-value applications for medical purposes.

With regard to more immediate production related R&D activities in industry the US based Cargill Dow produce biopolymers on a commercial scale, and also Mitsubishi and Du Pont is referred to have activities within biopolymers. In Denmark, Coloplast A/S and other companies within the medical industry are referred by Plackett, interview 2004, to be interested in bio compatible polymers. They are interested for qualitative reasons, for as to improve the medical and health functionality of their polymer products. But with the words of Plackett, interview 2004, the medical industry is never going to use megatons of plastics.

Medical uses of plastics are included in the Plastsammenslutningen's 20% of plastics used for other than: packaging (30 %), building appliances (20%), electrical and technical objects (15%) and transportation and other industrial applications (15%). Within packaging, the other interesting area for developing compostable plastics amongst other Jysk Vacuum Plast A/S and R. Færch Plast A/S can be found.

Biodegradable polymers have been mentioned especially with regard to the use for single-use tableware and packaging. Changing lifestyle and changing eating habits has been mentioned to increase the demand for sustainable food containers. The compostable alternatives of plastic table ware has been stated to both reduce waste and to reduce the use of fossil fuels. Characterising food packaging is that it is not suited for being recycled, or for being separated into specific waste fractions that can be treated separately.
In the Canadian report, Strategic Market Management System, 2002, the European market is estimated to depend on enforcement of regulation to use composting polymers, as well as taxes on fossil fuels. Further, it is estimated that large scale advantages will increase productivity in the biopolymer production.

Concerns regarding negative environmental consequences have not been a distinct part of the debate. One of the critics, mindfully.org estimates that the production of biopolymers will require 50% more oil based chemicals and toxic chemicals in the mix, softeners, colours, uv-protection etc. Also other concerns are mentioned by www.mindfully.org.

Another consequence of producing plastics from crops is the use of land that would otherwise be available for other purposes, for example food productions. A point which has been made even more distinct for bio-ethanol. The Danish activities are hard to place in a technology development context. However, the Danish activities can be seen as important for building up knowledge for both contributing internationally to the development of plastics and for knowledge building and transfer to Danish industry. The knowledge, transferred in the education of polymer scientists and PhD's may enable engineers in the plastic industry to follow, possibly influence and adapt to future developments.

This knowledge building may also be important for influence on policy making, in EU and elsewhere. Radical, and internationally directed initiatives seem to be important for influencing environmental innovation agendas in the plastics industry.

4.5.2.1 Environmental assessment of bio-polymers

As mentioned, the environmental claims of bio-polymers typically relate to the un-coupling of the production of plastics from fossil fuels and to degradability of bio-polymers as opposed to synthetic polymers. However, it should be emphasized that the manufacture of bio-polymers also implies the use of fossil fuels for supplies of process energy for manufacturing processes.

In assessing the environmental consequences it should also be noted that the manufacture of bio-polymers requires biological raw materials/substrates, typically originating from agriculture or forestry. Such organic matter is in general a priority resource to reduce society's environmental impact, especially global warming and other energy related impact categories. Manufacture of bio-polymers is, thus, not the only way to achieve environmental benefits from using biological resources in society – there is for example the opportunity of using such resources in the energy systems of society and substituting fossil fuels there.

Assessing the environmental implications of producing bio-polymers is, therefore, not just a matter of comparing bio-polymers to synthetic polymers of petrochemical origin, but also a matter of comparing to the lost opportunity of using the same biological resources for substituting fossil fuels elsewhere in society.

The degree to which the opportunity cost of using biological resources has to be included depends on the availability of the biological resources in question. If availability is limited compared to the potential uses of such resources, the opportunity cost would have to be included. Looking at a region like Europe and at the potential future needs to reduce the use of fossil fuels for energy purposes deriving from e.g. the Kyoto agreement, availability of biological resources seems to be limited.

There may, therefore, well be an objective of achieving the highest possible substitution efficiency of fossil fuels by organic matter. In plain language, we may be better off converting oil and gas and maybe even coal to polymers and organic mater to heat and electricity, instead of converting oil, gas and coal to heat and electricity and organic matter to polymers. As long as society uses fossil fuels for heat and electricity generation in large quantities, and as long as organic matter can be used to reduce fossil fuel consumption on this arena, other uses of organic matter may be judged on their ability to achieve a higher fossil fuel substitution efficiency than on this arena. And it yet remains to be proven that conversion of organic matter to polymers implies higher substitution efficiency.

In the holistic assessment of fossil fuel substitution efficiency, it should of course be noted that plastics in large parts of the world are incinerated with energy recovery, and the tendency to do so is increasing.

Within product categories and regions of the world, where waste disposal in nature is a significant priority compared to e.g. energy related impacts, there may be environmentally immediately justifiable applications of bio-polymers without considerations of fossil fuel substitution efficiency. Likewise, if the biological resource in question is found to be of unlimited availability, implying there is no opportunity cost of using it.

4.5.3 Bio-ethanol

The production of bio-ethanol has been another biotechnology development motivated by the possibility of partially substituting fossil fuels, reducing CO2 emissions and reducing/substituting the use of MTBE. Though bio-energy technologies have not been the focus in this survey, bio-ethanol will be mentioned shortly.

In Europe, according to BACAS, 2004, most of the bio ethanol is produced from fermenting sugars from beets and wheat. In the US and Brazil, producing 11% and 16%, respectively of the world’s bio-ethanol, corn and sugar cane is used for the production. Increasingly, BACAS states, waste materials are used for production.

The activities in Denmark are regarded as very modest compared to a number of other European countries (Haagensen, 2003 & Thomsen, interview 2004). Development activities are prominent at DTU, Risoe National Laboratory, The Royal Veterinary and Agricultural University, at Novozymes A/S, ELSAM and Green Farm Energy A/S. These activities have been publicly funded; the activities at Novozymes A/S with a grant from the American Ministry of Energy (DOE).

According to Larsen, Kossmann and Petersen, 2003 the possibilities for developing and producing bio-ethanol in Denmark are underdeveloped. As examples of this Thomsen, interview 2004, mentions France and Sweden to have prioritised the development of bio-ethanol much higher, reaping environmental benefits in the form of reductions of CO2 emissions, from these investments.

It has been stated by both public and private researchers (ao. Jensen, interview 2004, Thomsen, interview, 2004) that public funding is essential for the research and development within bio-ethanol, as is public regulation of the taxing and/or price system. Further the spurring of development and increased used of bio-ethanol, potentially in combination with fossil fuels, is referred to depend on publicly initiated changes in the energy system and in the pricing and tax system. This leads Larsen et al., 2003, in ‘New and emerging bioenergy technologies’, to suggest the key messages on driving forces to be:

- security of supply, based on to the use of domestic resources;
- local employment and local competitiveness
- local, regional and global environmental concerns and
- land use aspects in both developing and industrialised countries

and the barriers as being:

- lack of competitiveness of the bio-energy technologies – some being competitive others not
- the competitiveness is strongly depending on eg. the amount of externalities included in the calculations
- in general bio-energy needs to be moved down the learning curve
- resource potentials and distribution
- costs of bio-energy technologies and resources
- lack of social and organisational structures for the supply of bio-fuels
- local land-use and environmental aspects in the developing countries and
- administrative and legislative bottlenecks

Their recommendations are:

- modern bio-energy has large potential, both globally and for Denmark, but more R&D is needed
- Denmark has a long tradition of agriculture, highly qualified farmers and a leading industrial position in biotechnology, pharmacy, plant breeding, seed production, energy technologies and renewable energy. Together these factors give Denmark the opportunity to become the first mover on most key issues in modern bio-energy
- to exploit these advantages we deem it of utmost importance that Danish research institutions establish cross-institutional research platforms and co-operative interdisciplinary projects. Such projects should include as stakeholders politicians, industrialists and venture capitalists. In particular politicians must contribute by setting out the way for bio-energy, and supporting the transition from basic research to competitive technologies ready to enter the market.

These suggestions for developing ethanol are made with focus on the substitution of fossil fuels. But other considerations may be included in the assessment of the environmental aspects, as discussed in the following. In addition to comparing the environmental benefits with regard to CO2 emissions, CO2 emissions may have to be ‘weighted’ against land use for feed stock for the ethanol production, feed stock which may have been used for food, for fertilizer or heating (the use of agricultural waste).

4.5.3.1 Environmental assessment of bio-ethanol

A holistic environmental assessment of bio-ethanol as fuel for cars has been performed comparing it to conventional gasoline (Nielsen and Wenzel 2005). The assessment has included all cradle-to-grave changes in our fuel systems, including of course running the car, when producing and using ethanol from corn in USA as a substitute for MTBE and/or gasoline in conventional fuel. Figure 4.4 next page illustrates the result of the assessment. The figure suggests that there are both environmental benefits and draw backs when using bio-ethanol. Benefits are seen on the conventional environmental impacts from fossil fuel driven transport: global warming, photochemical ozone formation (photo smog) and resource consumption, whereas draw backs are seen on environmental impacts typical for agriculture: nutrient enrichment and acidification.

Moreover, producing bio-ethanol is not surprisingly seen to require extra land (for the corn production) compared to conventional fuel. This highlights the issue as outlined in the previous section on environmental assessment of bio-polymers, namely that there is an opportunity cost related to bio-ethanol production in terms of land use, or use of the organic material, corn. The land or the corn may well be used for other purposes that can achieve higher fossil fuel substitution efficiency than the conversion of the corn into ethanol by fermentation. The study referred here has been confined to the conditions for bio-ethanol production in USA, and this implies among other things that the substrate for bio-ethanol production is corn. This would most probably not be the chosen crop for a Danish situation. But the point made by the study is general, namely that there is the trade-off between the immediate advantage of e.g. the CO2-neutral fuel and the land used by production of the crop, and that this use of land/crop has an opportunity cost that very well may prove to be higher than the benefit. In fact, the opportunity cost was assessed in the mentioned study (Nielsen and Wenzel, 2005) and it proved indeed to imply an overall increase in environmental impact.

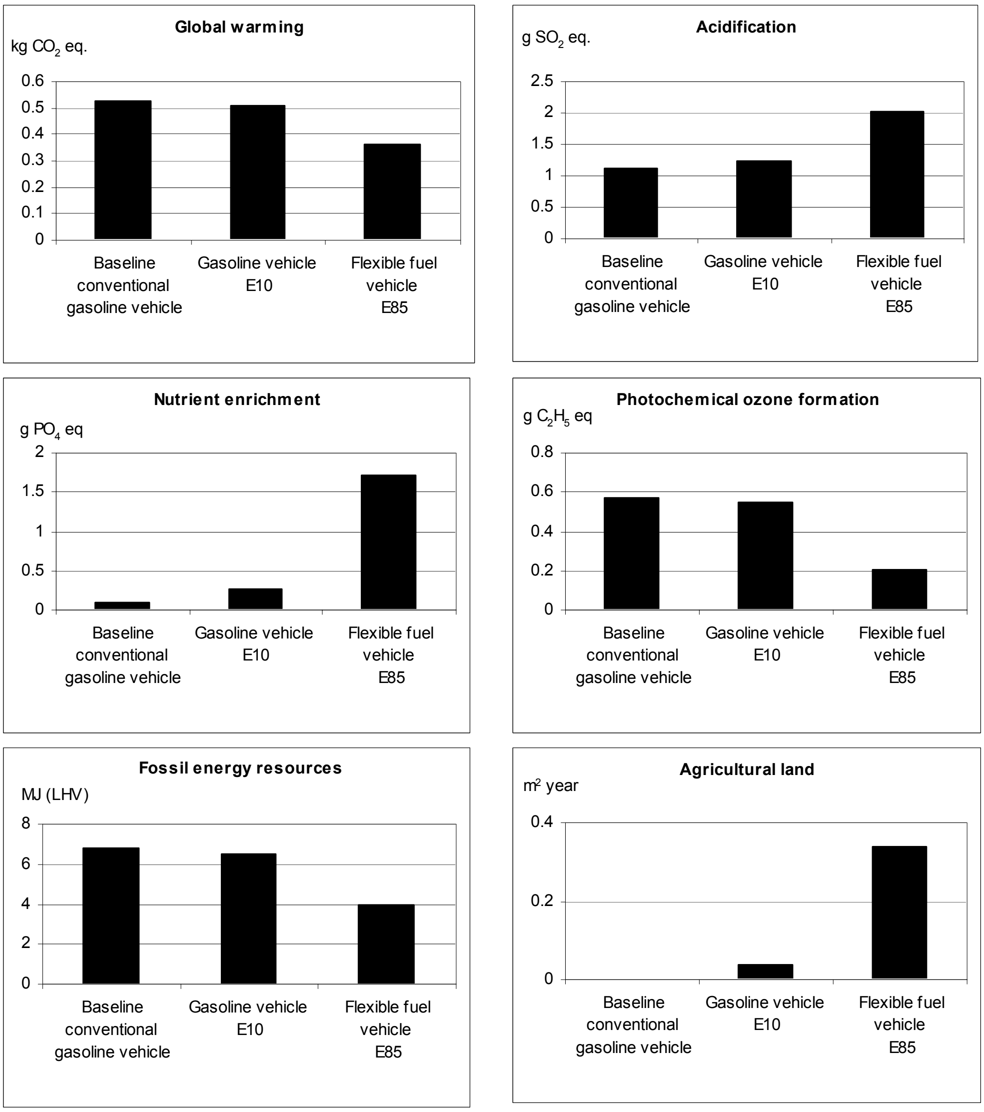


Figure 4.4
Contributions to global warming, acidification, nutrient enrichment, photochemical ozone formation and use of primary energy (LHV – Lower Heat Value) and agricultural land for driving 1.6 km (one mile) in cars fuelled gasoline mixed with 0% (baseline conventional gasoline), 10% (E10) and 85% ethanol produced from corn. Source: Nielsen and Wenzel 2005

4.5.4 Biological base-chemicals

A potential that was revealed by some of the interviewees was the fermentative production of base chemicals for multiple uses. One such example was succinate which is a substance having many potential uses as precursor for further chemical synthesis, one of which was polymerisation. Other such base chemicals may potentially be produced by fermentation – ethanol is an example.

The potential environmental benefits or draw backs related to these are, of course, to be judged by a comparison to chemical synthesis from petrochemical precursors. Given the rapid increase in fermentation efficiency compared to chemical synthesis, there may well turn up base chemical substances to be taken over by fermentation due to better cost-efficiency having in turn also better environmental efficiency.

4.5.5 Bio-remediation

New biotechnology used for pollution control and remediation, was mentioned early in the development of new biotechnology as an application area, and one of the early new biotech patents was the patent on an 'oil eating' bacteria issued in the 1970s.

Genetically modified micro organisms for remediation have been mentioned in policy documents on new biotechnology development since then, including the OECD report from 1994. And though there has been a shift in policy towards 'cleaner production' over 'end of pipe' solutions, the use of micro-organisms for remediation is still an issue, debated with regard to both its positive cleaning potentials, as well as the risks associated with these. Publicly undertaken activities as well as industry activities have been modest. IDA, 2000, identifies public research mainly at Aalborg University.

With regard to private activities, Novozymes A/S has bought up a number of smaller companies within bioremediation in the states, but states to have very little activity in Denmark.

The reason for the relative limited bio-remediation activities going on in Denmark, has been suggested to be uncertainty regarding environmental and health consequences, regarding economic consequences, and regarding regulation. The environmental uncertainties are also expressed in public opinion polls.

Research has consequently been scarce. The widespread conception in the research environments, that cultures of not modified micro organisms are regarded as doing a good job without being genetically modified, has contributed to lack of pressure for research and development..

This apparently also means that very little research has been carried out on the potential negative environmental consequences of the release of the micro-organisms. A further argument against the research in release has been the difficulties in doing this on release without releasing.

It might however be changing, or at least indications of an increasing interest is emerging. This indication of micro organism coming to play a role in future remediation comes from both public and industry actors, such as Novozymes

A/S with their investment in a number of US companies in bioremediation, and biotech regulators expressing to see and increasing industry interest. However, our interviews give the impression of hesitation, for exploring the potentials, especially with regard to risk. And though both private and public researchers acknowledge the potential negative consequences as a central concern for further development, both public and private research in the potential negative environmental consequences and risks are very limited and on the back burner for the time being.

Contributing to the low interest in carrying out more consequence research may also be that this research may not lead to a more widespread use. Research may reveal that the negative consequences outweigh the expectations to the positive effect.

Also IDA, 2000, in 1999 identifies possibilities in the long run, but point to the necessity for public investments. This reference also points to the necessity for risk assessments, which, within some areas, will require research in methods for to do so.

4.6 Discussion and summary statements

The often stated advantages for developing new biotechnology in Denmark – the large R&D activities in the public as well as in the private sector and a large agricultural based industry including a biological based pharmaceutical industry – has been mentioned also within the industrial and environmental area in addition to pharmaceuticals and plants.
In this chapter on the environmental perspectives in biotechnology we have looked at selected new biotechnology productions and applications with an assumed environmental potential. We have on the one hand looked at their potentials regarding:

- resource efficiency
- substitution of scarce resources/ exploitation of 'wastes'
- substitution of toxic chemicals
- detection, monitoring and cleaning

and on the other hand on the basis and conditions for exploiting the potentials with regard to:

- R&D and industry structure
- environmental regulation
- other societal developments

In our present characterisation of biotechnology, we have, as mentioned, limited ourselves to a selected number of applications, especially within the 'white' or industrial use of biotechnology. We have excluded both 'green' and 'red' biotechnology, and environmental aspects related to these.

The potential positive environmental perspectives have been the focus, and potential positive aspects have been the background for the selection of cases. We have discussed these, and discussed the terms on which these positive assessments were made. And raised some of the contrasts in these assessments, amongst other related to alternative uses of raw material. Potential negative consequences of applying new biotechnology have been touched upon as well. But very little has been referred to, regarding specific environmental consequences of new biotechnology.

4.6.1 Discussion of the environmental perspectives

As visualised in the previous sections, the environmental performance of biotechnology is not an unambiguous issue. The mere fact that biological resources are degradable and of biological origin does not in itself imply any indication that biotechnology is environmentally superior to its alternatives. It should be borne in mind that any environmental assessment of a technology is a comparison to the alternative pathway to provide the services in question, and that the alternative is most often a well matured technology having had a long period of time to achieve its level of resource efficiency.

This implies that up-coming technologies have to compete with matured ones, and often there has to be some kind of bottleneck to be broken for the up-coming alternative to be competitive. In the case of biotechnology, one such breaking of bottleneck is, of course, the genetic modification of micro-organisms implying huge efficiency increases of biotechnology, and there is no doubt what-so-ever that this will lead to the fact that bio-technology gains a lot of land from conventional chemical synthesis and products of petrochemical origin.

In the process of identifying the new fields of application, market mechanisms and economic reality will, of course, in the long run reveal where the benefits are. On the way there, however, research and development efforts may be more or less well put, and an up-stream assessment of the characteristics of biotechnology and its strong points compared to its alternatives helps to improve cost/benefit of the effort and eliminate unfruitful tracks as early as possible.

The *first* essential characteristic of biotechnology is the heavy increase in process efficiency of fermentation. This leads in itself to undisputable benefits in terms of resource savings and related environmental impacts from the manufacturing and use of these resources. Moreover, it rapidly renders new application areas of fermentation products economically competitive to their conventional alternatives and allows for harvesting any benefits related to using fermentation products in industrial and household processes worldwide.

Secondly, fermentation products within the concept of ‘white biotechnology’, especially enzymes, seem to have inherent advantages in terms of resource- and environmental efficiency. A quite large number of technically completely different enzyme applications have been studied, and there is an unambiguous tendency that enzymatic processes – in a holistic assessment – imply huge environmental and resource benefits over their alternatives. The underlying reason is probably that enzymes are active in such low doses, and that they can operate under a variety of conditions. The implication of this is that use of enzymes often leads to lower process temperatures and to substitution of much higher quantities of chemical auxiliaries. Moreover, enzymatic processes often lead to higher overall process efficiencies leading to savings of raw materials in general.

It seems, therefore, that there is a self-enforcing positive driving force in the combination of the facts that fermentation becomes increasingly economically competitive and that use of enzymatic processes in both industry and households have inherent advantages. In some enzyme applications, huge environmental benefits are found even at the global scale. Examples are enzymes in detergents lowering washing temperatures all over the world or enzymes in animal feed potentially eliminating phosphorus emission from agriculture. Most enzyme applications, however, even though the avoided environmental impact from introducing the enzyme solution is like 10 times higher than the induced impacts, will lead only to marginal environmental improvements when looking at the global impact of the enzyme application. Examples are using enzymes in industrial processes like the so-called stone-wash of jeans in textile industry, in leather processing and many other industrial processes. A more thorough investigation is needed in order to quantify the overall potential of enzymatic processes on the global scale.

Thirdly, however, conversion of organic matter in fermentation or other processing implies conversion losses. This is an important characteristic for both bio-polymer production and fermentation of e.g. ethanol. Combined with the fact that the substrate for fermentation or other conversion is not necessarily an unlimited resource, but may well be a priority resource for achieving environmental benefits in society in general, it means that there may be an opportunity cost of using the organic matter. The bio-polymer or bio-ethanol or whatever product of biological origin, shall in such cases, therefore, not only compete with the alternative product, but also with the alternative use of the organic matter. If we choose to make bio-ethanol out of agricultural product or even waste in e.g. Denmark, we do not take these resources from the field or dumpsite, we take them virtually out of the heat & power plants implying an increased need for fossil fuels there. This is crucial to realise, and the acknowledgment of it is not present in the discussion of this field of biotechnology application today. Looking at conversion losses in fermentation compared to incineration, it seems at the first glance that incineration has a higher efficiency of fossil fuel substitution than fermentation in the cases of bio-polymer and bio-ethanol production. The matter should be investigated in detail, and in the light of the ongoing efforts on both bio-polymer and bio-ethanol production, it seems urgent to do so.

Fourthly, though, biotechnology can often lead to substitution of specific chemicals that may be hazardous to the environment. The case of bio-ethanol – or ethanol in general – as octane booster in gasoline, is a good example. The use of ethanol to substitute MTBE is not an issue of overall energy balances, but an issue of targeting a specific unwanted chemical. In such cases, biotechnology may be a route to provide alternatives, but again it should be borne in mind, that alternative pathways of providing the chemicals exit, e.g. ethanol can be produced from petrochemical sources as well. Other examples of targeting specific issues is the bio-polymers' ability to avoid littering of plastics in nature, but again a holistic assessment should address whether measures to do so are superior to measures of e.g. establishing waste incineration with energy recovery in society. Probably both concepts have their place in the various regions of the world for a longer period of time.

4.6.2 Discussion of the structural conditions

Only a very limited part of new biotechnology development has been related to environmental benefits. Efficiency gains and especially product enhancements have spurred industrial development – and large projects of genetic mapping have been an important part of development as well.
The largest area of new biotechnology application, the pharmaceutical industry, has not been driven by an environmental advantage. There may in some instance be an environmental advantage from new biotechnology production in the form of resource savings; but this is not a main driver.

Regarding development of GM plants, this was not driven by environmental benefits. In the 1980s, environmental benefits were advanced by especially industry to be a consequence of introducing herbicide resistance into the plants. An advantage which is still an issue of heated dispute for several reasons.

Differently with the industrial biotechnology and biotechnology developed for remediation. It has since the 1970s and as mentioned in Naturkampen, 1981 and by the Danish Ministry of Environment in 1985, been regarded as having environmental perspectives. But, for a large part, has not been developed because of economic barriers: the application of enzymes has, in the short run or not at all, been economically efficient, without changed relations in the price structure or as a consequence of cost increasing regulation.

Research and development is, as mentioned, very unevenly distributed between areas, with pharmaceuticals taking the lead. The areas within 'environment' that we have selected cover only a very small part of new biotechnology development – app. between 5 and 15 percent of biotechnology research and development, and of the selected areas, enzyme research and development, covers far the largest share.

Enzyme development is in Denmark and in the world dominated by Novozymes A/S with more than 40% of production, and, with a rough estimate, at least the same share of R&D. As mentioned above, efficiency gains as a result of genetic engineering and increasing efficiency in fermentation processes account for the very large increase in enzyme production, also influencing the efficiency in the processes where they are used, and thus contributing to increased industrial enzyme applications to substitute chemical processes. (As will be returned to later, also regulation of the industries using enzymes in their process and rising energy prices for these, have been an important driver for the increasing enzyme production). Research and development within biotechnology has, as mentioned also above, within important areas been driven by industry; or private industry has at least been very important for the relatively large R&D capacity. Novozymes A/S has become an even more important driver of research within certain applications of biotechnology with their involvement (DKK 2 million per year plus a professorship financed by the Novo Nordisk Foundation) in the Novozymes Bioprocess Academy, the purpose of which is 'to enhance chemical engineering research and the education of graduates and researchers in the biotechnological field'

The concentration of knowledge and competences in very few companies, gives these a central role in the development and application of enzymes. Conditions for enzymes to be developed were by the companies mentioned as both relating to the industry structure, to environmental regulation and in selected cases to research and development support.

Regarding the industry structure it was referred that it is characterised by large markets served by industries with the knowledge and competences to engage in development and use of enzymes. Industries with these large players will more likely develop and use enzymes, whereas industries consisting of small companies/producers have less basis for taking part in development and use of enzymes. (Size is however not the only prerequisite, since large monopolistic players will be able to refrain from introducing more efficient and environmentally sustainable processes, if they have no competitors).

The Danish activities regarding the development of bio-ethanol and the development of biopolymers are still primarily publicly financed, though also carried out in private or semiprivate institutions. The potential substitution of fossil fuels with renewable organic material from agriculture or new crops, or from forestry, or from agricultural or forestry waste, are main arguments.

The projects face a number of uncertainties regarding the efficiency compared to existing technologies and to alternative uses of the organic materials to go into the ethanol and biopolymer productions.
In Denmark, the innovative activities are carried out by public institutions, in consultancies or similar institutions and no private research has been identified. This is in contrast to the general picture of the industry, in which private industry carries out majority of the research into biopolymers, with important activities in the US, Japan and Germany.

Within both areas, interviewees mentioned public initiatives as essential for development, with regard to technical developments as well as with regard to price regulation and infrastructure.

The Danish research in genetically modified organisms for remediation, monitoring and cleaning is, as referred, primarily public, and applied research estimated as very modest. Both public and private research directed at applications which require release, has been limited by the uncertainties related to the deliberate release and the consequent risks of gene transfer or the diffusion of genetic modified organisms. No applied research on these consequences have been indicated, and according to the Bioteknologikontoret, interview 2004, the government has no plans yet to initiate risk research related to these applications.

Companies and institutions within bioremediation, monitoring and cleaning have hitherto stated combinations of existing micro organisms to do the job sufficiently; and genetic engineering is not regarded necessarily as ‘solutions’ to specific difficult ‘jobs’. But according to Bioteknologikontoret, interview 2004, an increasing number of conference contributions on genetically modified organisms to be released for remediation, may indicate an increasing interest. But we have not identified drivers for an increased public or private interest in more application oriented research, except maybe reduction of environmental uncertainty regarding potential negative consequences.
Environmental regulation has been important for the increasing application of new biotechnologies. Though the application areas for the biotechnologies are diverse, and the structures for the different developments are differing in various ways, regulation is referred to, in most cases, to be important for the application. Few of the applications seem to have been introduced or gained ground, without some kind of political regulation or regulation to consider long term consequences. These regulations include both regulations to reduce work health or environmental effects, and the regulation of prices.

The demand for enzymes has been spurred by for example:

- regulation limiting or banning existing processes (bans on the use of certain chemicals in for example the tanning and leather industry),
- restrictions on release of phosphor into the environment as for example in the Netherlands and the ban on the use of meat and bone-meal

- price increases on the unwanted or less wanted scarce or toxic substances (for example regarding plastic waste)
- price increases (via political agreements and taxing) on oil and water, stimulating for example the development of detergent enzymes enabling lower washing temperatures

Governmental regulation, aiming at improving environmental sustainability and/or societal efficiency, has thus been an important prerequisite for commercial efficiency. According to Novozymes A/S, there are technically many opportunities for applying enzymes to reduce environmental strain, which will be spurred by regulation. However, Novozymes A/S for commercial reasons does not want to be specific about these potentials.

In addition, it has to be underlined that these regulations have to be international. Novozymes A/S's market and production is highly international, and enzymes are developed for large markets. High national standards may spur innovation, but not without expectations of larger markets. Introduction of regulation and standards in third world countries will be part of both ensuring market as well the environment, by improving industrial processes in these countries as well as avoiding relocation to these countries.
With regard to bio-ethanol:

- ban or out-phasing of MTBE
- substitution of oil schemes and
- taxing, either lower taxing of bio-ethanol of higher prices or taxing of fossil fuels
- have all been mentioned as contributing to the diffusion/increased demand of bio-ethanol.

The development of bio-ethanol and the diffusion of it/demand for it, has been largest in countries which have both allocated more substantial resources for the development of it and which have introduced tax exemptions on their use, as for example France and Sweden (for example Thomsen, interview 2004 and Enguídanos, 2002). In the US and Japan, out-phasing schemes for MTBE has been referred to having spurred substitution, including large investments in the research and development of bio-ethanol.

Regarding also bio-plastics, the prices of fossil fuels are important for the bio-plastics ability to compete – in addition to the technical problems in developing the different plastics material. The production and the potential taxing of bio-plastics and its alternatives is referred to have been important for diffusion also in other countries, as is the alternative uses of the feed-stocks. For degradable plastics to be developed and diffused, waste regulation and recycling systems have been stated to be important: taxing of waste being promotive of biodegradable plastics, recycling systems reducing the economic advantage of degradability, maybe except for special and medical applications. Increased regulation and cleaning needs are referred to as what may initiate increased research and development of genetically engineered organisms to supplement the use of non-modified cultures of micro-organisms. But at the same time the environmental regulation, responding to the large environmental uncertainties of releasing the organisms into the environment, limit application.

4.7 Policy aspects

In the chapter on the environmental perspectives of new biotechnology, in contrast to the chapters on nanotechnology and ICT, we have chosen to focus on areas where biotechnology has been pointed to as offering environmental potentials. For remediation, potentials have been pointed to since the 1970s; substitution or reduction of chemical use has been another vision for new biotechnology, as has the substitution of fossil fuels with biotechnology based products; and for the industrial applications, potentials have been known also before the break through of genetic engineering, but have become increasingly commercially interesting with the increasing fermentation efficiency in enzyme production and with increasing environmental regulation, and scarcity and price increases on water and oil/energy.

These visions have been prevalent – in research, in research programs, in the Ministry of Environment and in industry since the 1970s and 1980s. But research and development addressing environmental issues has been modest, whereas pharmaceutical applications of new genetic engineering and until recently, also plant research and development increased immensely.
A number of reasons may be mentioned in this relation, as well as possible policy suggestions.

New biotechnology research addressing environmental issues specifically, appears very little in public research. 'Environment' has not been a 'grant releasing concept', and both basic research and more application related research have been argued with other issues, not illuminating potential implications for environmental understandings or research.

Specific focus in research policy on environmental issues AND specific grant allocation to environmental issues may contribute to the analysis of possible environmental benefits, instead of the very vague environmental claims made in some of the first new biotechnology programs, which had very modest effect, if any.

Also within industrial innovation, visions have only slowly been realised. The biotechnology solutions have in many cases been more 'expensive' solutions , due to long development times, existing price structure of raw materials and common goods (water, air etc.), the existing acceptance of chemical and other agents, an industrial structure without the possibility of adapting the new techniques (size, competence structure etc.) etc.

The biotechnology solution can therefore either be supported with more direct support for technology development, as in the case of enzyme development for ethanol production, ethanol production or biopolymers, or indirectly, with more general regulation; the latter implying that biotechnology solutions compete with other technological and social solutions.

Government and international regulation of toxic substances and regulation of prices on scarce or expensive resources has been shown to be a strong motivator for green innovation by many, and both literature survey and actual biotech development indicate that this also goes for biotechnology development, and also will in the future.

Regulation, e.g. of hazardous chemicals was found to initiate the search for enzymes to reduce or substitute application of chemical substances. Though it was stated by industry to be dangerous to initiate development on the basis of expectations for regulation, introduced regulation seems to have been rather effective in bringing about environmentally sounder innovations. Examples have been mentioned within textile and leather, within fodder ingredients, and within pulp and paper, and Novozymes A/S, in addition to further development within enzymes in response to regulation, also expect regulation to be important for bioremediation. If new biotechnology will actually be the answer is not certain; but for a number of issues, Novozymes A/S indicate that enzymes may be developed – however without being open about which issues.

Governmental prioritisation through influencing the price mechanism, for example via taxes and fees may be another instrument for motivating both industrial and public green innovation. Price increases, politically or because of exploitation of scarce resources or both, have been a strong motivator for both research and development. Regarding biopolymers and bio-fuels, further government intervention in the price relations are stated by industry and researchers, to be important drivers for continued development. But these interventions obviously may change relations between technologies, industries and environmental focus. Therefore, such interventions may be based on continuous analyses of the possible environmental and other consequences, and the political weighting of these, as the example with the bio-ethanol amply demonstrates.

Regarding contained use under the existing circumstances little concern has been expressed in the surveyed literature and in the undertaken interviews . It has been expressed during the interviews that production of new and more enzymes, increased use of enzymes, use of new enzymes and the use of enzymes in new processes, need to be monitored. Research may need to analyse the potential consequences of releases from production, which may not only be a matter of monitoring but also a need for more basic research. The need for research into the environmental consequences of release of e.g. GMO for monitoring and remediation, has however been referred to, and the uncertainties regarding release referred to as inhibiting R&D into the potential developments. Research into these consequences may not lead to a more widespread use of new biotechnology for monitoring or remediation, because the negative consequences may outweigh the expectations to the positive effect. This research therefore cannot be expected to be carried out by industry, for economic and credibility reasons, but must be governmentally initiated and governmentally financed.

In general, the scarce and decreasing R&D resources in regulation and control may inhibit more proactive considerations of new biotechnology developments. This may be restricting also new biotechnology developments with environmental perspectives, since it contributes to increased industrial and societal uncertainty.

5 Nanotechnology development in Denmark – environmental opportunities and risks

Maj Munch Andersen with contribution from Stig Irving Olsen and Birgitte Rasmussen[9]

5.1 Introduction

Research and debate on environmental issues related to nanotechnology mainly focus on risk aspects. There are in recent years rising attentions to ethical, social and environmental concerns related to nanotechnology, making it likely that risk and ethical issues are going to be as important to nanotechnology as it has been to biotechnology. New regulations are considered and a serious of research projects are either coming out these years or are under way around the globe, noticeable the recent report from the Royal Academy (2004) and EC SANCO (2004). These reports have presented some of the so far most comprehensive research into the toxicity of nanotechnology, showing serious concerns related to nano particles.
Nano eco-opportunities are very often referred to in the literature discussing the scope of nanotechnology (but not necessary in the risk or technology assessment literature), often with very high expectations of considerable environmental advantages (Jacobstein, 2001,Wood et al. 2003, Nanoforum 2004, The Royal Society, 2003, 2004, European Commission 2004). These statements are, however, often of a very general and superficial character and more in depth studies are needed both on the scope and the dynamics involved.

The intention of this study is two fold: It seeks to investigate the dynamics of early *path creation* within nanotechnology; more specifically how environmental issues form a part of the search processes of the various actors in the emerging nano technological field in Denmark. This is in other words a qualitative analysis of the drivers, expectations and learning modes of the Danish nano innovation system.

It aims to identify (map) the eco-opportunities and -risks related to nanotechnology as perceived by the Danish nano researchers. It implies in other words a broad scanning which naturally limits the depth of the analysis of specific scientific and technology developments as well as their environmental implications. On the other hand it offers an opportunity to give a comprehensive picture of where the main innovation activities and search processes in the Danish nano community seems to be heading and by whom (which researchers and companies are involved). The mapping, then,

[9] The text draws on background research by my colleague Birgitte Rasmussen, Risoe, particularly on nano risks, and the written materials produced from the newly finished Danish Nanotechnology Foresight (Ministeriet for Videnskab, Teknologi og Udvikling 2004). Stig Olsen from IPU, DTU has particularly contributed with environmental assessments and Marianne Strange, project pilot at the Polymer Department at Risø National Laboratory has functioned as advisor on nanotechnology.

provides the broader context in relation to which the individual innovations should be seen.

The mapping also serves as a tool for networking in the nano community during as well as –hopefully- after the foresight project, as such a mapping of research activities in the Danish nano community has not been carried out before.

This analysis does not seek to discuss how green nanotechnology is or where the best eco-opportunities are. This task makes little sense owing to the very early stage of development and the highly diverse nature of nanotechnology. Since it is hardly yet a technology the uncertainties as to the future development are considerable. Rather, the analysis here focuses on analysing the early path creation and identifying the expectations on eco-opportunities related to nano science. By analysing path creation, the evolving lock-in into technological paths is highlighted. Hereby the directions of the search processes going on are sought captured. These indicate long term perspectives on the directions nanotechnology development may take in Denmark.

An innovation economic perspective is applied in the analysis of the nanotechnology development. Very few such studies at the microlevel of nanotechnology development have been made so far, so there is little analysis to build on or relate to, in Denmark or elsewhere. The analysis builds mainly on an interview based qualitative analysis combined with a broader mail based mapping undertaking within the Danish nano community.

The analysis looks into:

1. What is nanotechnology?
2. What do international findings say on environmental opportunities and risks of nanotechnology?

The path creation processes within nanotechnology in Denmark. Focus is on how environmental issues enter into the strategies and search processes of Danish nano researchers and related industry. The identification of nanotechnology eco-opportunities more generally and through case studies.

5.2 Nanotechnology – definitions and dynamics

This section seeks to present and characterize nanotechnology. A few comments are made on the innovation dynamics of nanotechnology and how innovation in nanotechnology is analysed in this report.

5.2.1 What is nanotechnology?

Nanotechnology is an emerging general purpose technology. It is expected to have widespread impacts on society by replacing or influencing existing materials and technologies. The scope of nanotechnology is as yet very uncertain but same have anticipations that it may form the basis of a new industrial revolution, i.e. disrupt and transform the existing technology platforms in line with the steam engine, electrification and computer technology.

Nanotechnology is commonly understood as dealing with very small things. A nanometer (nm) is indeed small, one thousand millionth of a metre. The significance of the nano scale is, however, not only that things are small, but that materials obtain new properties here. This is mainly due to two reasons. First, nanomaterials have a relatively larger surface area. This can make materials more chemically reactive and affect their strength and electrical properties. Second, quantum effects can begin to dominate the behaviour particularly at the lower end of the nano scale, which affects the optical, electrical and magnetic behaviour of materials.

Materials can be produced that are nano scale in one dimension, such as very thin surface coatings. Or two dimensions such as nanowires and nano tubes or in three dimensions such as various kinds of nano particles.

Nanotechnology is the design, characterisation, production and application of structures, devices and systems that entails controlling the shape and size at the nanometre scale.
The size range of nanotechnology is often delimited to 100 nm down to the molecular level (approximately 0.2 nm) because this is where materials have significant different properties. But it is disputed how strict to delimited nanotechnology. The need to integrate with other length scales to obtain wider technology development is emphasized.

Nanoscience is the study of phenomena of materials at atomic, molecular and macromolecular scales, where properties differ significantly frm those at a larger scale.

Since the 1990's the nanotechnology term has shot into the limelight. Research into and even technologies based on nano scale structures is, however nothing new.

What has led to a breakthrough and hence the rise of nanotechnology as a phenomenon is the development of new sophisticated tools to observe, measure and manipulate processes at the nanoscale level. These tools have emerged within the last 25 years. Noticable tools such as STM (scanning tunnelling microscope) from 1982, AFM (atomic force microscope) from 1986 and TEM (transmission electron microscopy), but there are nowadays a range of other tools. Before these tools research and development at the nano scale was experimental trial and error.

The new tools are leading to a greater understanding of and control of processes at the nanoscale and gradually the ability to design materials with specific properties. "Nanometrology", research into the ability to measure and characterise materials at the nano scale, forms the basis for nanotechnology. Research using and manufacture based on these instruments is then what constitutes the nanotechnological field.

Conceptually the rise of nanotechnology was laid out by the physicist Feynman in his lecture from 1959 "There is plenty of room at the bottom", foreseeing the possibility to examine and control matter at the nano scale. The term nanotechnology was first used by the Japanese researcher Taniguchi in 1974 referring to the ability to engineer materials at the nanometre scale. The driver was minituarisation in the electronics industry. Already in the 1970s nanostructures were created as small as 40-70 nm using electron beam lithography.

To day much of the research and development is still at the experimental stage (Lux Research 2004, Cientifica 2003).The commercialization of nanotechnology depends on laboratory experiments being turned into large scale, reliable and economic methods. Techniques and specific instrumentation for fabrication, control and measurement at the nanometer scale are under development but face major challenges. Concerning production methods two main routes can be distinguished:

- *Top-down approach:* Reduction in structure sizes of microscopic elements to the nanometer scale by applying specific machining and etching techniques (e.g. lithography, ultraprecise surface figuring)
- *Bottom-up approach:* Controlled assembly of atomic and molecular aggregates into larger systems (e.g. clusters, organic lattices, supramolecular structures and synthesised macromolecules).

Current commercial nanoproducts are based on top-down approaches while bottom-up approaches are still more, in some cases very, experimental. It is here, though, there are the big expectations of achieving efficient large scale fast production of nanomaterials which may form the basis of an industrial revolution. As yet though bottom-up manufacturing methods have not really materialized meaning that the uncertainty as to the connectivity and future paths of the nano technological field is highly uncertain. In the latter years we are seeing a beginning synthesis of the top-down and bottom-up approaches, a significant stage in the materialization of nanotechnology. Figures 5.1 and 5.2 illustrate some main features of nano production techniques are illustrated.

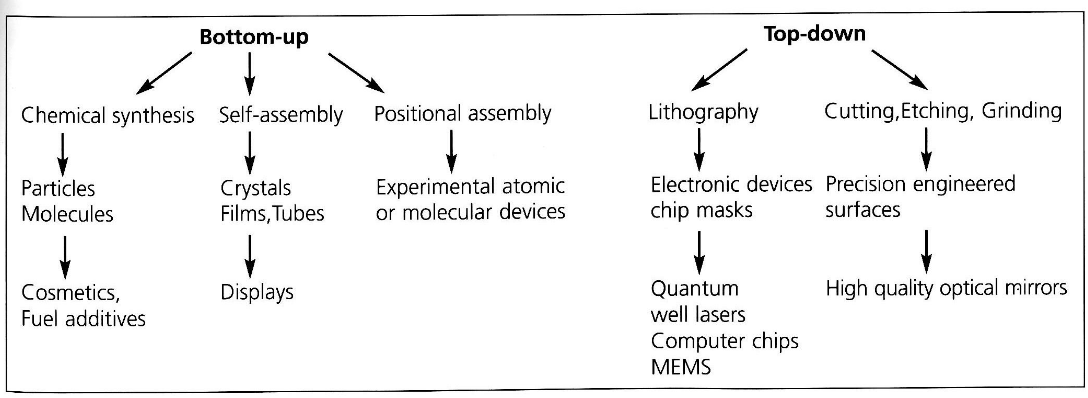


Figure 5.1 Bottom-up and top-down nano manufacturing techniques.
Source: The Royal Society, 2004 p.25

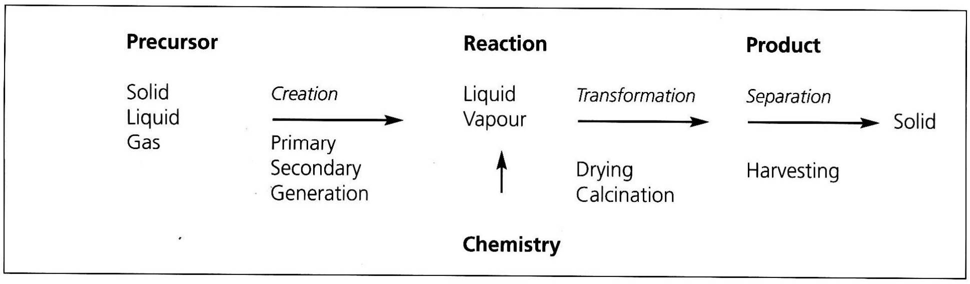


Figure 5.2 Generic processes in the production of nano particles.
Source: The Royal Society, 2004 p.25

In many ways nanotechnology is not á technology yet, and perhaps it never will be. It may more be characterized as a a platform technology rather than one distinctive technology entailing a wide range of very different fabrication techniques, as the figure illustrates. Indeed many refer consequently to nano technologies in the plural.

Adding to the confusion as to what constitutes nanotechnology is the multidisciplinarity of the field. Nanotechnology is based on a convergence during the latest century of basic disciplines such as technical physics, molecular biology and chemistry all trying to operate and manipulate at a nanoscale level, see figure 5.3. This common scale of operation and manipulation has opened up for a multidisciplinarity and combination of scientific paradigms leading to new research areas and possibilities for new technology development.

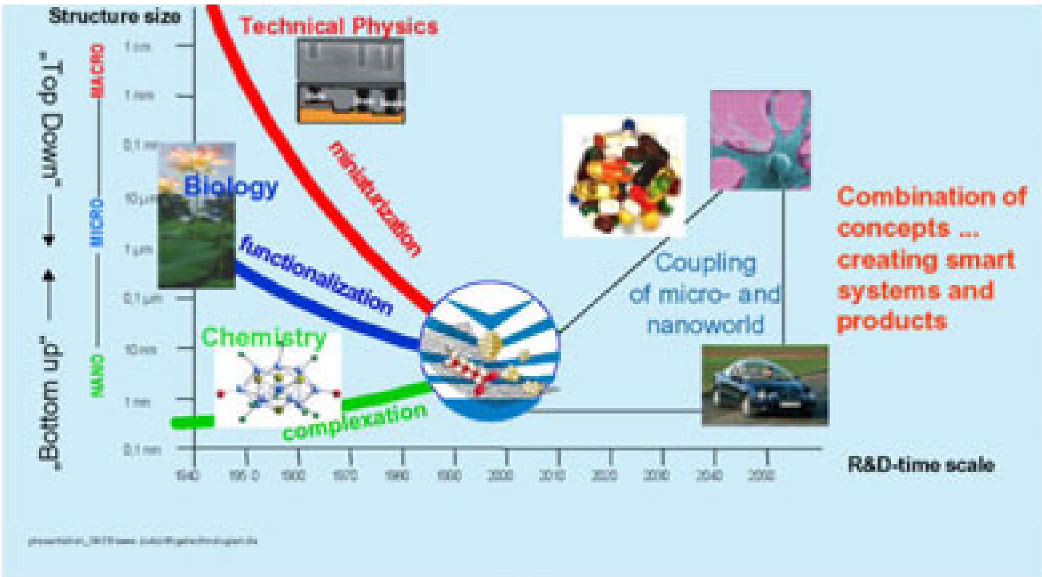


Figure5.3 Multidisciplinarity and combination of paradigms (Luther, 2004a).

The nanotechnological conglomerate may be divided into the following subsections: nanostructured materials, nanoelectronics, nanophotonics, nanobiotechnology and nanoanalytics, which illustrate the very diversity of the field (Luther, 2004b).

In short, here six characteristics of nanotechnology are pointed to that are important for the dynamics of nanotechnology development (see Cientifica, 2003, Selin, 2004, The Royal Society 2004, Wood and Geldart, 2003, Luther, 2004b):

- *A platform technology* charactherized by boundary problems, where it is contested what is nanotechnology and what is not. It is still discussed whether nano is a new technology or just a hype relabelling existing practices.

- The *enabling nature* of the technology. It is a very fundamental, (as fundamental as it gets) general purpose technology. There are expectations of wide systemic effects into practically any technology.

- The *immaturity and science based nature* of the technology. We are mainly talking about fundamental research. The industrial applications of nano science are in many cases only starting to take place and the scope of many potential (theoretically possible) nanotechnologies is highly uncertain.

- The *ubiquitous nature* of the technology. Being so small nanomaterials can be built into (existing or new) materials and devices to a high degree leading to converging (smart) technologies with multiple functions. It can, however, also be used to built completely new materials.

- The *cross-disciplinarity* of the field. Nanotechnology is the convergence of several natural scientific disciplines.

- The inherent *spectacular nature* of the technology. Nanotechnology deals with and changes fundamental aspects of life (atoms and molecules). There are frequent references of nanotechnology to "reshape the world atom by atom" or similar statements. Hype and phantasizing lead to great long term expectations but also confusion and uncertainty and serious concerns on the scope and societal and environmental effects of the technology.

In the Danish empirical analysis in section 5.4 we will return to these issues.

5.2.2 The nanotechnological development

Currently nanotechnology is hardly a technology. A lot of nano science has not materialised into technologies yet. Major problems remain on how to scale up slow research laboratory work to efficient industrial mass production. But internationally, investments into nanotechnology are rising tremendously, illustrating the high expectations to nanotechnology. There is an ongoing global race to be in the lead in a possible coming industrial revolution, currently with the US in front but Asia also very much on the move and the EU lacking somewhat after.

National and local governments across the world will invest close to $5 billion in nanotechnology R&D in 2004 (35% in the US, 35% in Asia, 28% in Europe, and 2% in rest of the world). Corporations will spend about $4 billion globally on nanotechnology R&D in 2004 (46% by US firms, 36% by Asian firms, 17% by European firms, less than 1% by companies in rest of world) (Lux Research, 2004).

Quite a range of products are already commercial, but mainly on a small scale, mostly based on top-down techniques; e.g. in cosmetics, textiles, paints and electronics, many are used in the automotive industry and mobile phones. E.g. in mobile phones nanotechnologies are used in advanced batteries, electronic packaging and in displays. Numerous forecasts have been made on the future development of nanotechnologies. The uncertainty is considerable but major breakthroughs are expected in a range of areas within the next 5 to 15 years though some developments may have even longer time perspectives (Lux Research 2004, Cientifica 2003).

5.2.3 Explaining path creation in nanotechnology

This analysis applies an innovation economic perspective on the nanotechnological development. Basically, the perspective pursued here seeks to place nano innovation dynamics within an innovation system perspective (Freeman, 1987; Freeman, 1995; Lundvall, 1988, 1992 (ed.); Nelson, 1993; OECD, 2000, 2002). The (national) innovation system perspective (NIS) entails a theory on the co-evolution of institutions, organizations and technology. Hence an innovation system is defined as "those elements and relations, which interact in the production, diffusion and use of new and economic useful knowledge" (Lundvall, 1992)[10]. The NIS perspective forms

[10] Innovation is commonly defined in the economic innovation literature as a novelty leading to value creation on the market.

today the basis of much innovation and research policy (OECD, 1999, 2000, European Commission, 2002).

A main question is how nano science is going to be caught up by the (national) innovation system when materialising into technologies. Who are the main actors, what are the drivers and what will the stages of development be? The empirical analysis in section 5.4 seeks to investigate the evolving “nano innovation system” in Denmark, i.e. how research institutes and companies interact in the production of nano knowledge under influence of and in interaction with the surrounding institutional set-up.

Nanotechnology is highly science based. Public research and none the least major multinational companies are currently the main drivers of nanotechnology development, (Lux Research 2004, Cientifica 2003). Being a general purpose technology, similar to the steam engine, electrification and ICT, it is very generic and enables other technologies rather than make up products in its own. Nanotechnologies may serve as e.g. raw materials, ingredients or additives to existing products. Even though nanotechnologies may physically only make up a small portion of various product they may in decisive ways influence on their properties. The nanotechnological development is likely to influence on practically all technology spheres but it is a question how much it will complement or replace existing technologies.

General purpose technologies, if materialized, make profound long term effects on the economy, i.e. create long waves in the economy. The gestation time may be very long though, often 30 to 50 years after the early breakthroughs (Freeman and Loucã, 2001). Wider effect on the aggregate economy only materializes in the mature stages of the technology. So far the economic impacts of nanotechnology are very limited. We are still awaiting a possible technological and economic take off following the current massive worldwide investments in nanotechnology.

The infancy of nano technology means that focus here is on early path creation, i.e. the early structuring of the field. Nano technology is very much in the *pre-paradigmatic stage*. In this fluid phase the uncertainty as to future innovation paths is great. It is uncertain whether the innovation will become a dominant design or not and there is risk of exaggeration. This makes is difficult to persuade other researchers, firms and investors to support the innovation (Teece, 1986, Lundvall, 1985). Creating confidence in a standard based on a trajectory that is hardly understood, such as nanotechnology may easily appear, is naturally associated with great difficulty. Such radical changes are slow and have to await a codification process and gradual acceptance of principles through multiple interactive learning processes between supporters and opponents.

In the very early stages of a technology, the standardisation activities are focused on the creation of a common language. Next, the performance expectations and procedures for inspection, testing and certification are addressed (Reddy et al. 1989). The codification process may possibly be succeeded by changes in education systems and other supporting infrastructure. In this stage there are weak appropriability conditions and imitation is strong. Market leadership is required to advance standards and it is often big players with a strong reputation who break the logjam among rival technologies and pull the complementary assets (technologies and capabilities) together (Chesbrough and Teece, 1996).

If we turn to the *paradigmatic stage*, as industry standards increasingly become accepted, economies of scale and learning become more important. Imitators with less developing costs and less restricted by asset specificities, rather than the innovators, may come to possess the dominant design and profit from the innovation (Teece, 1986). Since much nano technology is still only nano science or at the early experimental stage we are talking about very early path creation where industry standards are lacking.

Path-dependent learning implies that a research organisation or firm's knowledge base is theory-laden and upholding inner consistency. The basic argument is, inspired by Kuhn (1970) that technology development, parallel to scientific work, follows certain heuristics. Dosi (1982 p. 152) defines a technological paradigm as "a model and a pattern of solution of selected technological problems, based on selected principles derived from natural sciences and based on selected materials technologies", (p.152). *A technological trajectory is the pattern of conventional problem solving activity within a given technological paradigm*; i.e. it is the normal problem solving activity determined by a paradigm (Dosi, 1982).

The technological path (or trajectory) emerges because the technological paradigm embodies strong prescriptions on the directions of technological change to pursue (positive heuristics) and those to neglect (negative heuristics) (Dosi, 1982). The efforts and imaginations of researchers and practitioners are focused in precise directions while they are "blind" with respect to other technological possibilities. A technological paradigm defines an idea of technological "progress" related to the economic and technological trade-offs of a given technology.

Many elements in the innovation system contribute to the "seeding" of trajectories: "Microlevel entities path-dependently learn (and get stuck).., but sector-specific knowledge bases and country specific institutions restrict the 'seeding' of the evolutionary process ..... and also channel the possible evolutionary trajectories .... Given the initial conditions and the institutional context, these innovations spread and set in motion a specific trajectory of competence-building and organizational evolution" (Dosi and Malerba, 1996 p.15).

The core question addressed in this study is on studying the directions of the emerging nano technological trajectories and how environmental issues may form a part in these. The perspective suggested here is to analyze nano path creation dynamics by focusing on the shaping of researchers' and firms' *attention rules,* i.e. the routine focus of their research or technological development work depending on their entrepreneurial expectations, (compare Penrose 1956, Boisot 1995) and their *search rules*, i.e. their routine learning modes (Nelson and Winther, 1982). The formation of attention and search rules is placed within a wider analysis of the organisation of (nano) knowledge production within the innovation system (Lundvall, 1992 eds., OECD 2000). These aspects will be further discussed in the analysis of path creation in the Danish nano community in section 5.4.

To conclude, there are limitations as to how much can be said about emerging technological paths in nano technology given the current immaturity in technology development and great uncertainty as to the scope of the technology. We know in fact very little at present about how nanotechnology is going to materialize itself.

5.3 Nanotechnology - international findings on environmental risks and opportunities

5.3.1 Environmental risks related to nanotechnology

Until recently there has been very little research into nano related risks. Thus, health, safety and environmental impact assessment of nanoparticles and nano materials is encumbered with huge uncertainties due to lack of knowledge. There are, however, increasing attention amongst authorities to nanorelated risk issues and several surveys underway around the globe[11]. In the US national nano initiative, the by far biggest nano research program globally, it is stated that “increasing knowledge of the environmental, social and human health implications of nanotechnology is crucial” (NSET 2003 p.32). In USA, the Office of Research and Development at the Environmental Protection Agency has requested studies to be done on the environmental effects of nanotechnology. French (“ECODYN “) and Asian studies are underway, e.g. in Japan. In its proposal for a European strategy on nanotechnology, the EU Commission (2004b, p. 20) also emphasise the potential risk for human health and the need for research and precaution. A number of research projects on the safety of nanotechnology are being funded by the European Commission within the Fifth and sixth Framework Programme. Among these is the ongoing NANOSAFE project, which assesses the risks involved in the production, handling and use of nanoparticles in industrial processes and products, as well as in consumer products.

Concerns of nanotechnology are particularly related to:

- Their large surface area, crystalline structure and reactivity, which could facilitate transport in the environment or the body which may be difficult to control or could lead to harm because of their interactions with other elements. Some manufactured nanoparticles will be more toxic per unit of mass than larger particles of the same chemical.

- Ultrafine particles have a different biological behaviour and mobility than the larger particles, and there is not a linear relationship between mass and effect. It is likely that nanoparticles will penetrate cells more readily than larger particles.

- The “invisible” size of the particles being developed. Such particles could accidentally enter into the food chain, initially causing damage to plants and animals while eventually becoming a hazard to humans. An expected wide-reaching spread of nanomaterials in products and environment may make them difficult to contain and control (Nanoforum 2004, Jong, 2004, EC Sanco 2004, Royal Society 2004).

The evaluation of risks related to nano particles is complicated by the fact that they exist widely in the natural world already. E.g. resulting from photochemical and volcanic activity and created by plants and algae. Some of these are highly toxic. They have also been created as a by-product by man for thousands of years through cooking and combustion, more recently from

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[11] For an overview of these see chapter 7 in Nanoforum (2004).

vehicle exhausts. The question is then whether manufactured nanoparticles or the use of nanoparticles in new ways present new risks?

The most significant conclusion of the recent/ongoing risk studies is a likely health risk particularly related to *free nanoparticles* that may penetrate into the brain, lungs and other tissues and possibly cause cancer and other deceases. Nanotubes have properties quite similar to asbestos fibres which raises suspicion of a similar toxicity, (Royal Society, 2004, Nanoforum, 2004, Luther, 2004b, EC Sanco 2004).

Most of the risk studies, however, focus on health and safety aspects while the impacts of nanotechnologies on the environment have not been studied thoroughly yet. The Royal Society report concludes that "there is virtually no information about the effect of nanoparticles on species other than humans or about how they behave in the air, water or soil, or about their ability to accumulate in the food chains" (Royal Society 2004 p.X in the summary). They recommend that until more is known the release of nano particles and nano tubes to the environment should be avoided as far as possible and that a precautionary principle should be applied.

A series of environmental assessment analysis are under way around the globe but so far only few results are available. One of these is an on-going study from CBEN –Rice University examines the behaviour of TiO_2-nanoparticles and carbon nanotubes in the environment with emphasis on the interactions with other chemical species. Following on from this, researchers will work on transport and aggregation of nanoparticles as well as their interaction with biological systems (CBEN, 2004). It has been seen that fullerenes could migrate through soil without being absorbed (Nano-forum, 2004). On the other hand not all nanomaterials were mobile in water. The mobility is very case specific (www.nanotechweb.org, 1. april 2004).

A rare example of a finished study is on the ecotoxicological effects of the carbon molecules called "buckyballs" (fullerenes) showing that these cause brain damage in fish at concentrations of 500 ppb (Oberdörster, 2004). It matters what kind of nanotechnology we are talking about and how ithey are used. According to Put (2004) the following classification can be used for the purpose of mapping out risks related to nanotechnology:

- Nanostructures from whatever nature (nanopatterns, nano-ordering, nanoparticles) that are *immobilised* at the surface or in the bulk of a matrix material. These kind of nanostructuring creates very little risk as the nanostructures or nanoparticles are fixed in a matrix.

- Nanoparticles that *are free* and can become airborne to form an aerosol. Depending on the shape of the particles, they can be breathable and upon inhalation cause adverse effects. These effects are related to the enormously enhanced surface to masse ratio and all properties related to surface will be multiplied with a huge factor.

- Supramolecular nanosystems, built up via *self assembly*, mimicking natural systems. Although these nanosystems might look like natural systems, there is one essential difference; they are not self-replicating and it is unlikely that self-replicating systems will be built up on short notice. There seem currently to be less concern with the so-called "Grey Goo fear" of uncontrolled self-assembly as pointed to by Drexler (1991).

- Nanosystems of *natural origin*. Natural nanosystems can be extremely dangerous or poisonous. As these systems are self-replicating or belong to self-replicating organisms and moreover as some of them are continuously modifying themselves via exchange of genetic material (e.g. viruses), these nanosystems have to be considered as the most dangerous on this planet, although this is not perceived as such. Genetic modification of certain natural systems is done because it can enhance beneficial properties substantially (e.g. enzymatic catalysis). However, new insights in genetics led to the conviction that not all consequences of even simple genetic modifications can be predicted; therefore, genetic modification should be limited to micro-organisms for which containment is possible.

The above categorization says, however, little about the environmental impact of different nano manufacturing techniques and thereby also of different nanotechnologies and nanomaterials. Of this very little is known so far. The Nanoforum 2004 report states: "Differences in size, shape, surface area, chemical composition and biopersistence require that the possible environmental impact be assessed for each type of nanomaterial. The long-term behaviour of such substances and their effects on elements are thus extremely hard to foresee".

Table 5.1 summarises the results of an environmental assessment performed in Germany by IÖW on the different nano manufacturing methods, one of the few studies made on this so far. As shown it is anticipated that risk of release of nano particles is low for most productions and uses of nanomaterials. Highest risks occur in work environments when processing airborne nano particles. However, even if the release from materials may be low, a widespread use of nanotechnology may possibly lead to a dispersion of significant amounts of nano particles. We need to know more about the behaviour and potential hazards of artificial nano particles in the environment.

Table 5.1 Nanotechnological products, their probable manufacturing process and their potential hazards.

Nanotechnology based products	Nanostructure	Manufacturing process	Potential hazards	Industrial sector
Application Area: New Surface Functionalities and Finishing				
tribological layers: e.g. superhard surfaces	ultrathin layers; nano-crystallites; nano particles in an amorphous matrix	vapour phase deposition, PECVD	PVD/CVD production process: risk of disposal of nano-particles is small (process is running in a vacuum environment) use stage: low scale disposal of nano-particles possible	Engineering, automotive
thermal and chemical protection layers	ultrathin layers; organic-inorganic hy-brid-polymers; nanocomposites	vapour phase deposition; sol-gel		aerospace, automotive, ICT, food
self-cleaning and antibacterial surfaces	ultrathin (polymer) layers, nanocrystallites in an amourphous matrix	vapour phase deposition, sol-gel, soft lithography		textile, ICT, food, building, medicine...
scratch resistant and anti-adhesive surfaces	ultrathin layers; organic-inorganic hybrid-polymers	sol-gel; SAM	use stage: low scale disposal of nano particles possible	building, automotive, textile, consumer goods
products with "nanoparticle effects" : e.g.	nano-particles, ultrathin layers	flame assisted deposition, flame hydrolysis,	production: deposition possible;	building, automotive, consumer

colour effects in lacquers		sol-gel	use stage: low scale disposal possible	goods, textile
Application Area: Catalysis, Chemistry, Advanced Materials				
catalysts	nanoporous oxides, polymers or zeolithes; ultrathin layers	precipitation, sol-gel, SAM, molecular imprinting	not known	chemistry, automotive, environmental, biotech
Sieves and filtration	sintered nano-particles, nanoporous polymers	self assembly, colloid chemistry		chemistry, environmental
Application Area: Energy Conversion and Utilisation				
fuel cells	ceramics from sintered nano-particles	div.	not known	energy, automotive
Super-capacitors	Nanotubes, nanoporous carbon aerogels	div.	nanotubes possibly toxic when inhaled	energy
superconductors	ultrathin layers	e.g. vapour phase deposition	production: risk of disposal is small	energy, medicine
Application Area: Construction				
nanoscale additives: e.g. carbon black in car tires	nanocrystals and –particles	flame assisted deposition, flame spray pyrolysis	production process: disposal of nano particles possible, danger of inhaling for workers; use stage: low scale disposal of nano-particles possible	building, automotive
Application Area: Information Processing and Transmission				
nanoelectronic components	ultrathin lateral nanostructured semiconductor	PVD, CVD, lithography	PVD/CVD production process: risk of disposal of nano-particles is small	ICT
Displays	utrathin layers	PVD, spin-coating		ICT, automotive
Application Area: Nanosensors and Nanoactuators				
sensors: e.g. GMR-sensors	metallic ultrathin layers; ultrafine tips	CVD/PVD/MBE; etching, SAM	PVD/CVD production process: risk of disposal of nanoparticles is small	automotive, engineering, ICT, analytics
Probes e.g. for scanning tunneling microscope	utrathin layers, ultrafine tips and molecules	PVD, etching, SAM		analytics
Application Area: Life Sciences				
active agent carrier: e.g. drug carriers	organic molecules, nanoporous oxides	self assembly, anodic treatment	flame hydrolysis production process: disposal of nano-particles possible; use stage: particles might be absorbed dermally; very small TiO_2-particles possibly toxic	Pharma, medicine
Cosmetics: e.g. pigments	utrathin layers from nano-particles, (amorphous) nano-particles	wet-chemical separation; colloid chemistry		cosmetics
sunscreen	nanocrystalline	flame hydrolysis		cosmetics

		titanium dioxide (TiO_2)			

Source: Haum et al., 2004.

5.3.2 Environmental impacts in the product cycle

Life Cycle assessment is an environmental management tools for assessing the environmental impacts of a service or function. All use of materials, resources and energy as well as all emissions from the processes in the life cycle are aggregated and interpreted in terms of their impacts on the environment and health, e.g. their contribution to global warming, acidification etc.

As described above specific concern is related to the release of free nanoparticles. An inventory of possible sources of potential particle release from the use and production of nanoparticles can be made by addressing the life cycle from nanoparticle generation to end products and finally disposal. It shall be stressed that due to the variety of different production methods, the process conditions vary widely and thus in principle the risk of potential particle release has to be considered separately for each different process. The following main steps can cause unintended release of nanoparticles: (Luther, 2004c, p. 44-48):

Nanoparticle production: Processes working at high temperatures or with high energy mechanical forces, particle release could occur in case of loss of containment of the reactor or the mills. The large quantities of nanopowder could be released in a short time into the atmosphere. Moreover, when sealing is broken, reactive mixtures can be put in contact with air and in some cases cause violent exothermic reactions. Failure of collecting apparatus are also important sources of potential release; this apparatus must be able to stop the nanoparticles and to evacuate effluents produced from the processes.

Collection of nanoparticles: Risks are increasing during the collection of nanoparticles particularly in a dry form. When opening collecting apparatus or reactors, nanoparticles can be released and airborne dispersed due to their high volatility. In gaseous atmosphere the behaviour of dry nanoparticles is primarily determined by the balance between attractive and lift forces. Gravity force has no noticeable effect on nanoparticles. Therefore, nanoparticles may be an air contaminant for a long time potentially being an inhalation health risks. When handling small particles the conditions for dust explosions may arise, especially in case of metal powders. Once dust has formed into the proper mixture with air, it can be ignited by energy from various internal or external sources. During the collection of solid nanopowders special care must be taken with regard to ventilation at the working place. Air streams could disperse nanopowders to form aerosols.

Cleaning operations: Nanoparticle release can also occur during cleaning operations of reactors, after the disassembling, when nanoparticles have to be removed from stainless steel pieces, windows or filters. Cleaning is usually performed using solvents or water, tissues, brushes or sponges, which are then discarded in garbage cans.

Handling and conditioning operations: Risks related to this kind of operations can be release of nanoparticles while producing ceramic pieces, particularly when the compressed nanopowders or coatings are formed.

Waste disposal: This includes the total production equipment that has been in contact with nanopowders at the different production steps. Disposal of the waste might be a potential source of nanoparticle release into the environment if no special care is taken with traceability and final disposal or combustion of the wastes.

Final product utilisation: When final nanoparticle based products are obtained, risks depend on the way in which nanoparticles are integrated. For nanostructured materials, nanoparticles are linked to a matrix by a thermal treatment at high temperatures. However, under wearing conditions particle release is likely to occur but dissociation of matter at the nanometric scale is unlikely.

Some of the fundamental features of nanotechnology which are essential for the new opportunities nanotechnology offers may also be a drawback when it comes to risks. We have a natural fear of what we cannot see, cannot control and cannot understand. And this is how nanotechnology may easily appear.

5.3.3 Policy initiative on nano environmental risks

Existing regulation indexing chemicals and measuring new products toxicology need to be adapted to the special properties of nano materials. According to Nanoforum (2004) nanotechnology leads to a need for new norms, standards and testing procedures for assessing risks to the environment and health (e.g. for nanometer length scales, calibration of instruments, health effects of nanoparticles, toxic effects of nanometer size of particles rather than on their chemical composition).

Considerable amount of attention is recently being devoted to the issues of regulation and legislation of risks related to nanotechnology particularly in USA and Europe. However, practical set-up of new legislation or adaptation of existing legislation is still in its infancy. It can be said that most countries and international institutions are still in the phase of raising awareness and investigating what the regulated topics should be (Nanoforum 2004).
The European Parliament's Industry, External trade, Research and Energy Committee has called for a study on the need for new regulations on nanotechnology while the same subject is to be discussed by the UK's Parliamentary and Scientific Committee.

In the nanostrategy of the European Commission from 2004 the following actions are recommended in relation to public health, safety, environment and consumer protection (p.20):

- to identify and address safety concerns (real or perceived) at the earliest possible stage
- to reinforce support for the integration of health, environment, risk and other aspects related to R&D activities together with specific studies
- to support the generation of data on toxicology and ecotoxicology (including dose response data) and evaluate potential human and environmental exposure
- the adjustment, if necessary, of risk assessment procedures to take into account the particular issues associated with nanotechnology applications
- the integration of assessment of risk to human health, the environment, consumers and workers at all stages of the life cycle of the technology

(including conception, R&D, manufacturing, distribution, use and disposal) (European Commission 2004b)

The Danish Nano action plan made by the recent Nano Technological Foresight suggests that there should be a focus on studies of possible health hazards and environmental and ethical aspects associated with nanotechnological industrial processes and materials and other applications of nanotechnology (Videnskabsministeriet, 2004). The Nano Action Plan "recommends that as an integrated part of each individual project, funds should be allocated to research and competence-raising relating to the environmental, health and ethical issues raised by nanotechnology, and that the responsibility for this should rest upon the research environments that receive project funding. Projects should only be granted funding if they address the environmental, health and ethical aspects in a responsible manner" (Ministeriet for Videnskab, Teknologi og Udvikling 2004).

5.3.4 Environmental opportunities related to nanotechnology

There are often very high expectations as to the environmental benefits from nanotechnology in nano reports and policy statements (see e.g. The Royal Society, 2003, Masciangioli, 2002, Nanoforum, 2004, Luther, 2004b, NSET 2003). In fact there are few nano reports if any, which do not mention environmental opportunities as a core benefit of the technology. This is also the case with the recent Danish Nano Foresight report (Videnskabsministeriet 2004). There seems in other words to be an unusual strong linkage between nanotechnology and environmental benefits.

Some of these reports point to some fundamental features of nanotechnology with eco-potentials. E.g Nanoforum (2004), argue that self-assembly, i.e. the attempt of mimicking nature's intrinsic way to build on the nanometre scale molecule by molecule through self-organisation, has eco-potentials:
"This "assembling" method is extremely efficient and could be helpful for the conservation of nature and natural resources. It is expected that the concept of "self-assembly" could be an approach for a sustainable development in the future. However, such futuristic concepts are far from being realised at present or in a medium term view (Nanoforum 2004 p.39).

Another report points to the energy efficiency of nanoparticles:
"The most relevant effect of nanoparticles for energy applications is the large amount of the atoms exposed on the surface compared to the bulk material. The large surface area leads to a high reactivity with low material use, which is useful for better catalysts (leading to higher reaction rates, lower processing temperatures, reduced emission or need for less material), for improving combustion processes (higher efficiency, lower processing temperatures, or higher absorption rates for light" (Nanoform, 2003, p.89).

The big US National Nano Initiative holds a strong overall green vision:
"Nanoscale science and engineering can significantly improve our understanding of molecular processes that take place in the environment and help reduce pollution by leading to the development of new "green" technologies that minimize the use, production and transportation of waste products, particularly toxic substances. Environmental remediation will be improved by the removal of contaminants from air and water supplies to levels currently unattainable, and by the continuous and real-time measurement of pollutants" (NSET 2003 p.32).

Another grand and quite green vision is expressed by a nano roadmap of the chemical industry stating that in the longer term it is hoped that "nanomanufacturing will encompass genuine "green" concepts of zero waste and little or no solvent use incorporating life cycle concepts of responsible products coupling biology with inorganic materials" (www.ChemicalVision2020.org).

Jacobstein (2001) and Reynolds (2001) pinpoint perhaps most sharply four main features of nanotechnology that are likely to lead to environmental benefits:

- The atom-by atom construction of nanotechnology will allow the creation of materials and products without dangerous and messy by-products.
- Most products of nanotechnology will be made of simple and abundant elements, e.g. carbon is the basis of most nanomanufacturing.
- Less materials will be needed because nanomaterials are stronger and thinner
- Cheap nanomaterials of very high strength to weight ration could mean a marked drop in energy consumption e.g. in transport.

Malanowski (2001) referring from the results of a workshop similarly concludes that the ecological benefits of nanotechnology could be very large in the form of:

- A preservation of resources is expected through the production of minituarised products which with a smaller material expenditure fulfils the same functions as conventional products.
- Energy savings could be achieved in transport through weight and volume reduction of products and by the reduced consumption costs of energy sparing electronic production processes.
- The use of wear resistant machine parts, corrosion-proof materials, nano-lubricants and/or nanotechnological procedures for the smoothing of surfaces contributes to the service life extension of machines.
- New materials will show a larger stability with comparatively small specific weights than conventional materials and will likewise contribute to the preservation of resources and e.g. reduced fuel consumption in cars.

The claims, as here, are often of a quite general and theoretical character, and many analyses are merely based on workshops rather than thorough analysis. There is a lack of more careful and systematic in depth studies of the extent and nature of the eco-potentials. This is naturally related to the early stage of development of the nanotechnologies and the associated high uncertainty. It seems to be too early to be very specific about where the opportunities are. And/or the eco-opportunities have not been looked into properly so far.

Numerous more specific potential environmental benefits of nanotechnology are pointed to in the literature, though more as examples and visions than an attempt to be comprehensive or to identify the most significant environmental potentials. Some of the frequently mentioned are (The Royal Society, 2003, Masciangioli, 2002, Nanoforum, 2003 and 2004, Luther, 2004b, Antón, et al 2001, Malanowski, 2001, European Commission 2004, NSET 2003):

Reduction of energy consumption

- Through a) better insulation systems using nano porous materials, b) more efficient lighting, nanotechnological approaches like LEDs (Light Emitting Diodes) or QCAs (Quantum Caged Atoms) are much more energy efficient c) more efficient combustion systems, d) the energy consumption in the mobility sector can be reduced by the use of lighter and stronger nano structured materials (see the automotive industry below), e) synthetic or manufacturing processes can occur at ambient temperature and pressure.

Develop more efficient or renewable energy production

- The degree of efficiency of combustion engines is not higher than 15-20% at the moment[i]. Nanotechnology can improve combustion by designing specific catalysts with maximised surface area.
- Nanotechnology is important for the development of hydrogen energy systems in several ways. Attempts are made at developing fuel cells powered by hydrogen fuel. The catalyst in fuel cells is nanostructured materials consisting of carbon supported noble metal particles with diameters of 1- 5 nm. Suitable materials for hydrogen storage contain a large number of small nanosized pores. Therefore nanostructured materials like nanotubes, zeolites or alanates are under investigation.
- Nanotechnology can help to increase the efficiency of light conversion in solar cells by specifically designed nanostructures (the implementation of Nanodots). A widespread use of solar cells suffers from the high costs of purchase. An alternative nano technological approach under development is low cost solar cells using titanium dioxide nanoparticles as light absorbing components (Grätzel cells) which may allow for more decentralised energy supply systems.

Reduction of resource consumption in the production or user phase

- Nanoparticles in paint can induce new properties to the paint, e.g. cooling effects, self cleaning and self repairing surfaces
- Nanotubes (or fibres build from them) can be used as reinforcement for composite materials. Because of the nature of the bonding, it is predicted that nanotube-based material could be 50 to 100 times stronger than steel at one-sixth of the weight if current technical barriers can be overcome.
- Strengthening of polymers in order to produce new materials with less consumption of raw materials which can substitute existing materials
- Reduced use of rare resources, e.g. precious metals, or toxic substances in catalysts.
- Textiles with nanotechnology finish can be washed less regularly and at lower temperature

Improved cleaning of air, water and soil

- Through the development of new environmental catalysts and improved catalytic processes. As well as improved capability to tailor nanostructured membranes offering new opportunities to selectively extract contaminants from air, water and soil.

Improving recycling

- The use of batteries with higher energy content or the use of rechargeable batteries or supercapacitors with higher rate of recharging using nanomaterials could limit the battery disposal problem.

- Integration of nano-chips in materials and products containing information about material properties and composition can be used for recycling purposes. (There are, however, also arguments that multifunctional nanoproducts may be difficult to recycle).

Better monitoring

- Nanotechnologies are expected to enable the production of smaller, cheaper sensors with increasing selectivity, which can allow continuous measurement and be used in a wide range of applications, e.g. monitoring the quality of drinking water, detecting and tracking pollutants in the environment.

Reducing the environmental impact of the automotive industry

- One area where nanotechnology is expected to contribute with major eco-innovations is in the automotive industry (Nanoforum 2004). Rising traffic density means that transport remains a major environmental problem and the car industry is increasingly looking for new solutions, also among nanotechnologies. The car industry hence belongs to the earliest users of nanotechnology. The automotive industry is in other words an area where there are some more substantial insights and experiences with developing eco-innovations based on nanotechnology. These are therefore dealt with more in detail in the following. Some products mentioned below are already on the market, others are at the experimental level.
- Energy consumption and waste is reduced by replacing metals with lighter materials. Nanoparticles are used to improve the strength of lighter metals or of steel, so that less metal is necessary.[1] Or using polymers reinforced with nanoparticles making them stronger per unit weight.
- The rolling resistance of tyres is lowered saving energy, and the durability is improved by use of nanoscaled carbon black saving waste.
- The combustion can be improved by homogenous and large area spraying of the petrol. An injection system with very fine holes (Nanojets) is under development.
- The engine lubrication is optimised by new nanoparticle-based lubricants and through micro- and nanostructures on the inner surface of the cylinders.
- The engines efficiency is optimised by use of higher temperatures and pressures. Nanotechnology can help to develop materials which are resistant to these conditions.

- Use of environmental more friendly energy systems in cars. Thermoelectrical elements based on nano-crystalline layers of semiconductors with low bandgaps may use a part of lost heat in the future. Cheap (e.g. Dye solar cells) or more efficient types of solar cells (e.g. by the implementation of Nanodots) can be used in the roof for operation of specific modules (e.g. for air conditioning systems), possibly be enlarged to the whole chassis. Experiments with cars driven by fuel cells are extensive.
- Reduction of air pollution caused by exhaust gas. Nanotechnology can contribute to the further reduction of pollutants by

nanoporous filters, which can clean the exhaust mechanically, by catalytic converters based on nanoscale noble metal particles or by catalytic coatings on cylinder walls and catalytic nanoparticles as additive for fuels.

- Developing new understandings of molecular processes that take place in the environment, e.g. how contaminants move through the environment, is also highlighted as an important environmental benefit of nanoscience (NSET 2003).

Overall, the environmental benefits of nanotechnologies are as yet not described in very great detail, and life cycle assessments are often lacking, i.e. investigating the environmental impacts of nanotechnologies over the complete supply chain including disposal.

A few case studies have been made looking more in depth at the eco-potentials of nanotechnology, noticeable a recent German life cycle assessment study (Steinfelt et al., 2004). They have analysed four case studies: Nano varnish, nano innovation in styrene synthesis, nano in the display sector and nano in the lighting sector. The study illustrates that at this point it is very difficult to make high standard quantitative assessments of the environmental impact of nanotechnologies due to lack of knowledge, incompleteness of available data on a given product or process and the high uncertainty as to the future technology development.

The most important recent environment assessment report , the earlier mentioned Royal Society report (2004) does not look into the eco-potentials, except for stating that "it is important to substantiate such [environmental] claims by checking that there are indeed net benefits over the life cycle of the material or product" (Royal Society 2004 p.32). They recommend a series of environmental assessment studies be undertaken on existing and expected developments in nanotechnologies by independent bodies.

Policies towards nanotechnology, e.g. EU's nano strategy, and the Danish suggested nano action plan, mainly focus on risk issues when dealing with environmental impacts and do not aim to address barriers to eco-innovation. So although the eco-potentials of nanotechnology are highly praised they seem rarely to be promoted by policies. An important exception is the US National Nano Initiative where "Nano Scale Processes for Environmental Improvement" makes up one out of nine Grand Challenge Areas for prioritized research, compare also the already mentioned strong green vision of the research program (NSET 2003).

Interestingly a first international initiative "International Consortium for Environment and Nanotechnology Research (I-CENTR)" has been created recently which looks at both negative and potentially positive environmental impacts of nanotechnology. The consortium studies the environmental applications of nanochemistry, nano-scale materials and processes in the environment, nanomaterial interactions with organisms and environment and generally sustainable ways for nanotechnologies. This consortium gathers approximately 30 researchers from different French and US universities and it is adding groups in Germany, Switzerland and England. Currently the actual extent of nano research and development targeted at eco-innovation is not known[12]. To conclude, also when it comes to eco-potentials there are many

[12] In Australia, the ARC Centre for Functional Nanomaterials has a strong focus on eco-innovation see Http://www.arccfn.org.au

visions and claims related to nanotechnology but there is so far limited knowledge on the more specific potentials of nanotechnologies.

In section 5.5 when focusing on the eco-potentials identified by Danish nano researchers, the eco-potentials will be discussed further.

5.4 Danish findings on path creation in nanotechnology

This section presents the main empirical findings on the role of environmental issues in the search processes of Danish nano researchers and industry. The empirical analysis undertaken is a first scoping study into the actors and dynamics of nanotechnology development in Denmark based on an interview round in the Danish nano community. No prior innovation analysis of this character has been made before, so there is little data to build on or relate to. Given the broadness of the technological field there are limits as to the depth of the analysis possible within this relatively limited project. The emergence of the Danish nano community
In recent years much is happening in the nano area in Denmark. Several new nano research centres and networks are springing up. The biggest ones are Nano•DTU with the major subcentres -MIC, COM, ICAT and CAMP at the Technical University of Denmark, iNANO at the University of Aarhus with links to Ålborg University and the Nano-Science Center at the University of Copenhagen . Some of these have been around for a while, 10-15 years, others are new. Also several transdisciplinary “nano educations” and PhD schools have been established and with great success, despite the general declining interest in the natural sciences among students. At the structural level, then we clearly see the emergence of a nano research community.

These new centres reflect that some Danish funding in the latter years have been earmarked to nano research, last year 60 mio. DKr, making the “nano” term increasingly attractive to researchers but forcing the nano researchers to join groups to apply for the money. There is little tradition in Denmark for large focused research efforts. Recently The Danish Basic research Fund and the new High Technology Fund is changing this somewhat, illustrating a stronger political interest in research and noticeably high technology in Denmark, including none the least nano research. There are therefore expectations of more funding going into the nano field. As an input to the priorities of the High Technology Fund, the recent Danish nano technological foresight has suggested to focus the nano effort into two strong nano research centres with a budget of at least 100 mio. DKr/year. The outcome of these research strategic processes is, however, as yet unknown.

But how much hype and how much scientific novelty is related to this nano trend? The Danish nano researchers generally are sceptical about the hype related to nanotechnology and its implications. To a large degree many feel there is nothing new in nano. They do the research they have always done but now it is redefined as nano.

On the other hand the same researchers also have expectations of nano science leading to greater changes in technology development and for some even expectations of an industrial revolution, albeit of a more evolutionary character. There is, in other words, a widespread sense of novelty and expectations of new industrial opportunities. Quite many, however, express scepticism about the scope of industrial effects, and warn that the hype may lead to too high expectations to nanotechnology and a back lash, especially in the short term.

At the more cognitive level, even though this may not be recognized by the individual researcher, a general conclusion of this analysis is that *attention rules* are changing as still more researchers, and more hesitantly people in industry, look towards "the bottom" leading to new problem definitions.
And also *search rules* are changing in important ways. Partly because researchers applying the new nano tools towards their research area are growing new understandings of how the size (of clusters) matters for the properties of materials. Theory building and modelling is replacing trial and error experimentation in a range of areas, eg. catalysis. Partly because of the transdisciplinary nature which is recognized as taking a central role in much nano science. It seems researchers from various disciplines find new grounds to meet at "the bottom" and synthesize their disciplines in new ways.
Danish researchers expect that the major innovations springing from nanotechnology will be related to the boarder areas between different disciplines, especially between biology – learning from natural systems- and physics/chemistry. New more transdisciplinary paths are therefore to be expected. The effect of this, new search rules in various nano related technological areas are, however, only in the making. The uncertainty about the direction of nanotechnological paths at this time is still huge.

In all, there are overall signs of new patterns of problem-solving activities emerging meaning that nano is not only a language (a redefinition of existing practices), it is a technological trajectory, a trajectory that is however, strongly shaped by the expectations associated with the nano hype.
These conclusions are likely to apply generally to nanotechnology and not only to Danish conditions. In fact Danish researchers state that there is no such thing as a specific Danish approach to nanotechnology; it is basic science and very international and regional specialisation is limited. There are of course key Danish competencies and perspectives as we shall return to.

5.4.1 The organisation of the nanotechnological knowledge production in Denmark

Much too is happening on the organisation of nano knowledge production as the field starts to shape up which calls for a deeper investigation. Here only a few preliminary observations will be made.

The Danish innovation system is generally fairly low tech. There is a specialisation on relatively low and medium tech products and an overweight of small companies and few really big companies. Still Denmark belongs among the more innovative economies and is doing quite well, none the least through user-driven innovations and further developments of products, albeit little engaged in radical innovation (Lundvall, 1999, the Innovation Scoreboard 2004). This raises questions as to the potential and conditions for building competencies on nanotechnology in Denmark given that nanotechnology belongs among the most science-based and high-tech technologies.

The Danish Nano Foresight Report especially points to characterization as the core competence within nano science and nanotechnology (Ministeriet for Videnskab, Teknologi og Udvikling, 2004). That is understanding and describing the phenomenon of nature and physics, while there traditionally has been less focus on synthesis that is the use of these understandings for the creation of new materials and other technologies. The core nano competencies identified are within traditional natural sciences such as theoretical physics, quantum physics, optoelectronics, scanning probe microscopi, X-ray diffraction and biomolecules. Measured in publications the Danish nano research is at a medium level seen in an international context, but it is in the top on some areas such as catalysis. It has been less good at translating this knowledge into industrial applications. This is, however, seen as an advantage, as nanotechnology development is taking place closer to the world of fundamental physics research than the traditional industry world (Ministeriet for Videnskab, Teknologi og Udvikling, 2004).

Still, some nano researchers criticize the Danish nano research for being generally too little oriented towards industrial application. A researcher at the Technical University states: “In Denmark nano research is about understanding, modulization and characterization more than manufacturing. What we are in want of in Denmark is a center for the design of nano materials. There are companies around the world becoming rich from selling nano tubes, fullerenes and tailor made materials. I see no reason why we shouldn’t make this in Denmark”.

There are some facilities and companies involved in nanomanufacturing in Denmark. E.g. Danchip is Denmark’s leading facility for micro- and nanotechnology, who uses conventional silicon integrated circuit technology for new areas within micro and nanotechnology. Danchip is a part of Nano•DTU. It has however, not been possible to make a mapping of the Danish nanoequipment and manufacturing facilities in this study.

Innovations based on micro/nano fabrication technology play a rising role over the last few years: “Danish Micro- and nanofabrication points both to applications within telecom and improving the bandwidth of the Internet, but also to new exciting possibilities with lab-on-a-chip applications, where complex diagnoses could be performed directly at the practitioner’s office.” (Professor Jens K. Nørskov, head of Nano•DTU)

The Danish nano research primarily takes place within the main public universities and research institutes in Denmark, compare the mentioned nanocentres and networks, i.e. mainly within the Technical University of Denmark (DTU), the University of Aarhus (AU), the University of Copenhagen (KU) and Risoe National Laboratory, and some what less so at the Royal Veterinary and Agricultural University of Denmark (KVL), Ålborg University (AAU) and Southern Danish University (SDU). Also the technical institutes (“Godkendte Teknologiske Institutter”) are to some extent involved in nano research with a strong application orientation.

With one exception research within business so far plays a minor role, although the relatively few big and research oriented manufacturing companies in Denmark to various degrees are involved in nano science and technology development and cooperate with the universities. Most important are companies within catalysis, medico and pharmacy, somewhat less so the advanced machinery and electronics industry and food ingredients. We are talking about in all less than ten big companies who are involved in nano research, and who are in a formal collaboration with universities, often in the form of co-financing PhDs. Some of these companies are, however, quite important to Danish nano research. Several nano researchers express that they miss the local presence of more big companies with strong scientific competencies to widen the opportunities for collaborative research with industry.

The one big company standing out by playing a central role in Danish nano research and technology development is Haldor Topsøe, a world leading producer of environmental catalysts and steam reforming. Haldor Topsøe has 30 years of experience with large scale nano based production within catalysis. Catalysis is a traditional nano scale technology, being well developed through experimentation long before the talk of "nano science" started. Much of Haldor Topsøes research and technology development has accordingly been based on experimentation. The new understandings originating from the rise of nano science the last 10-15 years are only beginning to make an impact on the Haldor Topsøe technology development, and they are still waiting for major breakthroughs resulting from this.

Haldor Topsøe has a very close relationship with the Danish research institutes, especially at the Technical University (Nano•DTU) and University of Aarhus (iNANO), somewhat less also Risoe. The relationships are formal and so close they could be called symbiotic. Haldor Topsøe pursues a conscious strategy of promoting Danish nano research and education, which they see as a necessary investment to them.[13] They not only collaborate with research institutes but also seek to strengthen these. E.g. in 1987 they took the initiative together with DTU to start the research of Surface Science at DTU. This later materialized into CAMP and later also into the ICAT center in 1999 focusing on catalysis. These and also the new Danish Research Foundation centrer CINF (Center for Individual Nanoparticle Functionality) are very close collaborators with Haldor Topsøe A/S. Halder Topsøe also invests in equipment at the universities, e.g. a new Electron Microscope costing 25 mio. Dkr. It is central to Haldor Topsøe's competitive strategy to have a better understanding than their competitors of the catalytic processes.[14] Haldor Topsøe is characterized by the nano researchers as being unique in its long sightedness and very strong research orientation, originating back to the founder's strong passion for research. Ib Chorkendorff, head of the ICAT and CINF centre, states:

"A company like Topsøe is different because of the philosophy there, which is very research based. Our competitors in Germany and England for example also cooperate with companies but these don't have the same interests in research. You can see a difference in the labs. The other catalyst plants haven't used so much money on equipment; they can't make the interesting investigations that Topsøe can make. This is what makes them so interesting as learning partners. We can talk to them directly. There are people there doing the same kind of research as we do. It is also interesting for our candidates who can see a career opportunity. This is what makes Topsøe a unique company. The close ties with industry are essential for our research. He emphasizes the need to continue and strengthen the shift from the trial and error approach to more fundamental research within catalysis in the rising global competition:

"We don't have a chance to compete with the Chinese who mix lots of potential catalysts over and over again looking for successful candidates. We need to find out what exactly the problem is, look at the physics behind it and then find out something new".

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[13] Interview w. Michael Brorson, Haldor Topsøe
[14] Interview w. Michael Brorson, Haldor Topsøe

General contact and cooperation with business various considerable, some nano researchers have hardly any contact, others quite a lot. Industry links are somewhat stronger at the application oriented Technical University and Risoe National Laboratory than at the traditional universities. A new analysis undertaken for the Danish Ministry of Science, Technology and Innovation confirm that these two institutes are in the lead in Denmark when it comes to business contacts, spin offs and commercialization of the research undertaken generally[15]. The large Nano•DTU center seeks consciously to promote technology transfer to companies and has collaborations with around 50 Danish and international companies[16]. Relations to business seem to be changing. "I see things are changing these years. Fifteen years ago the opinion was that here [at the university] we were to perform research at the highest level and educate people to the highest level, and that wouldn't be possible if companies were involved. Today university researchers are much more open to interaction with business." (Researcher at iNANO.) Another researcher at iNANO states: "Earlier we had very little contact with industry, but now [since joining a think tank on nano application opportunities in the food industry last year] relations are very good. It has been quite an eye opener to learn about their needs".

The Danish nano foresight report mapped 54 Danish companies working with or showing a strong interest in nanotechnology (Ministeriet for Videnskab, Teknologi og Udvikling, 2004). Most of these are small spin-offs from the universities and/or small companies within nano instrumentation and measuring. Additionally, we have the early users of nanotechnology, i.e. the large innovative companies in Denmark, who cooperate with nano researchers on many of their projects. Actual industrial application of nano research is, however, still limited. Generally, the industrial uptake of nanotechnology is very limited in Denmark with the exception of the field of catalysis, in which, as elsewhere in the world, we are still far from widespread industrial application and up-scaling to mass production.

Also company attitudes towards cooperation seem to be changing. When discussing perspectives for a wider industrial nano development in Denmark, Professor Besenbacher, Head of iNANO states: "I am very positive about cooperation with industry. It merely requires openness and a visionary attitude among the leading Danish companies. I clearly sense a considerable interest for nano, an interest which has increased over the past years. I think that the companies gradually realize that universities are leaders in this field, and they thus have a tremendous interest in interacting with us."
A greater role is, however, expected from the established companies than new ones. Professor Besenbacher states: "The future role played by small start-up companies is yet unclear. The challenge is to go from fundamental blue sky research to industrial production, and with a time horizon of three years, there is no proof of concept, making it difficult to obtain financing in Denmark. It is much easier to attain risk capital in the US".

A range of small, dedicated nano companies, however, have emerged, as illustrated by table 5.2 in section 5.5, especially within sensors, nanometrology and nanoparticle production. These are typically spin-offs from the universities/research institutes. Their role in the uptake of nanotechnology in industrial production remains to be seen.

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[15] Evaluering af Forskerpatentloven, Videnskabsministeriet 2004b.
[16] According to Britt H. Larsen, vice director of Nano•DTU.

5.4.2 The Danish learning relations

The rise of the nano technological field is changing the learning relations in Denmark in important ways. Ib Chorkendorff, Head of ICAT at the Technical University states: “It is not a single or particular event or invention that has happened, which makes nano into something special, because we operate within the same circles as we have done the whole time focusing at the atomic design. If I should say something about the nano hype it is more that it leads to greater fragmentation; because every university wants its own nano centre.The new nano constellations mean that things have become more rigid. Cooperation between the new nano centres has to some degree diminished, particularly between Århus/Jutland (iNANO), and the research environments on Zealand (especially the Technical University). At the new Nano Centre in Copenhagen they are now also looking towards Sweden (the Øresund region) for new cooperation opportunities.

The new regional nano centres to some degree disturb existing knowledge relations, since the thematic specialisation does not follow the regional clustering closely. In other words nano research into the same themes is performed in more places in Denmark.

All in all, the new nano centres have a marked impact on the organisation of knowledge production, both negative and positive. On the positive side, the new nano centres are valued by the researchers within them, particularly because they facilitate interdisciplinary work. Actually bringing together researchers from various fields on a daily basis creates new opportunities for in-depth, long-lasting collaboration. The interdisciplinary way of working is surrounded by excitement. For example, a project on biocompatible materials at the iNANO centre in Århus bought together a molecular biologist, a physicist and a medical doctor. In the beginning they did not understand each other due to their different scientific backgrounds, but now they are getting somewhere: “It is quite new for us to operate with the interaction between solid surfaces and cells and proteins, but it has opened up completely new possibilities and has been quite exciting”, (Researcher, iNANO centre). Nano•DTU, the largest cross disciplinary center for nanotechnology in Denmark, was established in 2004 to create synergy between the different research groups working in nanotechnology at the Technical University and use competencies and nanofacilities across departmental walls. More than 170 researchers are members of Nano•DTU, coming from 9 different departments and around 14 different research groups, illustrating the wide research span of nanotechnology.

The nano centres have had a major positive impact on the ability to attract funding, researchers and interest from companies. The iNANO centre, although only 2½ years old, sees a clear advantage in being well branded both nationally and internationally, especially in being more visible to companies. Generally, learning relations between various departments at the same university/research institutions working with nano seem to be quite strong and are strengthened by the new shared nano profile and the need to join forces to look for funds. Learning relations with international learning partners are also important, especially EU partners in order to apply for EU funding. It is less relevant when it comes to cooperation with industry.

Nano-related research takes place at all Danish universities, at least if we do not define nanotechnology too rigidly. Research outside the new centres have problems in attracting funds and attention, e.g. for researchers at the agricultural university.

Generally, the nano researchers appreciate the nano innovation system in Denmark as it is now: A researcher at iNANO states: “Research today is related to money. We must be able to attract the best researchers and the best equipment. Despite the small amount of funds I believe we can make a difference because we are a small nation. We practically all know each other. The same goes for the industry. The research leaders are scientists whom we know from our common university studies. I can pick up the phone and call, for example, the top people at Lundbeck directly. Our research groups have a non-hierarchical structure, as opposed to the Japanese structure in which two PhDs from different groups are not allowed to talk to each other without the permission of their respective boss. Our openness will be a decisive factor when the interdisciplinary projects are fully up-and-running.”
A researcher at the Technical University says: “At the moment it is excellent to do nano research in Denmark within my field [catalysis]. It is necessary to have a momentum, though, and you need fairly big groups to do this.”

5.4.3 Attention rules and entrepreneurial expectations

The nano research undertaken in Denmark is only partially driven by demand. To quite a wide extent, perceptions of possible application areas related to the research are quite weak. There is, in other words, an absence of entrepreneurial expectations in these cases and very little (technological) direction to the research undertaken.

The drivers for the choice of research focus, for the interviewed nano researchers can be grouped into the following five categories:

- They do fundamental research.
- They are driven by an interest in understanding the dynamics at the nanoscale level in various ways.
- They are interested in doing something which has a big technological impact, i.e. which will affect many people (scope) or lead to major change (i.e. the hydrogen society).
- They are interested in solving serious problems, noticeably health care and energy supply, less so environmental issues.
- They are interested in themes which are important to Danish companies.

Partly because they are interested in strong local learning partners. Partly because they want to strengthen Danish industry and secure that the public Danish investments in research are turned into value creation in Denmark.
They do research where they expect most funding to be found.
They see regulation as an important driver of research and development, particularly in the energy and environmental area (for the catalysts and energy researchers only).

The limited application approach by some researchers can be illustrated by this statement by an iNANO researcher: “Your end goal is not to make, e.g., a window which is self-cleaning, and then you start from scratch. Through research you suddenly obtain results which you may use to make a window. What we work with is definitely relevant for keeping surfaces clean, whether it is for an industrial machine or a window is up to the industry“.
Another researcher describes the mix of inputs involved in forming the research agenda: “Our ideas rise from interplay with colleagues, and the interaction with Danish and international companies is increasing. I would like

to have money for fundamental blue sky research, but it is also satisfying when what you do have applications.”(Researcher from iNANO).

The nano path creation seems to become more pulled and less pushed related to the rise of nanotechnology: Professor Besenbacher, Head of iNANO states: “There is nanoscience and there is nanotechnology. There is no doubt, that what we mainly do is nanoscience. We are inspired by an interest in understanding things at the molecular level. But I feel we are beginning to focus more on possible applications which could become nanotechnology”. Research at the nano centres at the University of Aarhus and University of Copenhagen seems to be more of a fundamental kind. At the Technical University, the nano research spans from fundamental research to applications. At Ålborg and Risoe there is a greater emphasis on the engineering part of nanotechnology, i.e. making devices.

Several of these researchers express an intererest in doing research that has an interest to Danish industry. For these researchers then, the demand side is quite important in shaping the research agenda also for the more fundamental research, but the demand side being industry rather than consumers.
There is, however, one application area which is a central focusing device. The by far dominating attention by Danish nano researchers is towards medico appliances; perhaps as much as 80 pct (a rough estimate) of the research is in some way oriented towards medico. This goes for all nanotechnology areas, i.e. nano modified materials or composites, functional surfaces, sensors etc. where it could be feasible. These research areas, then are very little oriented towards other applications, despite the fact they often have very wide application potentials. Issues such as biocompatibility, bacteria detection, antibacterial surfaces and drug delivery are at the center of most Danish nano research. A researcher at iNANO explains: “The research funding is so that we hardly have any basic funds for research, so we must find suitable projects. You must define an application area when you apply for research grants, so you need to state something. Nanotechnology is expensive and you thus have to become engaged in high value areas such as medico”.

The medico focus is so strong that it is not contested. It is the routine focus of most Danish nano researchers, so certainly we are talking about strong attention rules here. Naturally it is important here that Denmark has a very strong medico industry with some of the biggest players in Danish industry.

Three other application areas are important, but they all spring from the same competence, catalysis. The core Danish competencies in this area means that chemical production, hydrogen production and fuel cell research and environmental catalysts (heterogeneous catalysis) are important research areas, particularly at the Technical University, Århus University and Risoe. At Risoe, the declared research strategy of the laboratory is energy production, so here most nano research is somehow related to energy production, e.g. new materials for windmill wings or organic solar cells. Even here there is quite some medico oriented research too, though.

The research agendas are quite stable, not least because of money:
”We don’t just pick up a new theme. You need a critical research group before you can start a new project” (researcher at iNANO).
The core Danish competencies pointed to are clearly catalysis.

“Indisputably, we carry out outstanding research in the catalysis area. There is a fantastic dialogue between the research environments and the company Haldor Topsøe. Here we have all the preconditions for being successful” (Professor Besenbacher, Head of iNANO).

Similarly, Professor Nørskov, Head of Nano•DTU states that:
“We have succeeded in Denmark in making a really healthy combination of fundamental science and developing new products coupled to companies, especially Topsoe. Many countries would like to copy this Danish model; e.g. the US Department of Energy invited me over when they were going to develop a new strategy for their catalysis research. So I think we have a rather unique situation.”

But expectations in the medico area are high too. Professor Bjørnholm, head of the Nano-Science Center at the University of Copenhagen states:
“I believe that the biggest potential is in bio nanotechnology where we have a really good basis in Copenhagen. It is mine and Tue Schwartz’ [professor at the medical university in Copenhagen] vision that the platform created through biotechnology known as Medicon Valley in the Øresund [Baltic] region should be further developed with nanotechnology. In ten years we will have a strong nanotechnological medico hub here, propably the only one in northern Europe.”

Also the field of energy technology is seen as a central emerging competence within nano research in Denmark. “Denmark has an outstanding position for contributing to the development of new nano-based technologies in connection with hydrogen as a fuel. The knowledge base at Nano•DTU and at Risø is outstanding and several small and larger companies hold key positions in the field. This is true in hydrogen production where Topsøe are world leaders, it is true for fuel cells where Risø, DTU, the companies Topsøe and IRD fuel cells and other players are strong in various subfields, and it holds in hydrogen storage. Here DTU and Risø are very active and where a new start up is just beeing created by Nano•DTU researchers. Nanotechnology is at the heart of hydrogen technologies since nanoparticles are the workhorses in all the energy conversion processes" says Jens Nørskov, director of Nano•DTU.

In the suggested Nano Action Plan of the Danish Nano Foresight seven high-priority areas within nanotechnology were identified (Ministereriet for Videnskab, teknologi og udvikling 2004). Within these areas it is suggested that Denmark should built its core competencies in order to obtain a translation of nano science into industrial application, achieve increased growth and employment, and make solutions for important societal needs (in non-prioritised order):
Nanomedicine and drug delivery
Biocompatible materials
Nanosensors and nanofluidics
Plastic electronics
Nano-optics and nanophotonics
Nanocatalysis, hydrogen technology, etc.
Nanomaterials with new functional properties
Nano medicine is the only application area highlighted, the others are more fundamental nanotechnologies which cover quite a broad spectrum of the nano technological field. Environmental issues are not particularly addressed but catalysis and hydrogen technology, existing strength holds, are.

5.4.4 Attention and perception of environmental issues

Core Danish competencies, those related to catalysis, are strongly related to environmental issues in the form of environmental catalysts for gas cleaning (heterogeneous catalysis). Haldor Topsøe holds 70 pct. of the world market in this area. Given this core Danish competence there is surprisingly little spread to other environmental areas from the Danish nanoresearch. There is in fact very little "environmental nanotechnology" (termed this way by a researcher at the agricultural university), where environmental issues are defined as a target or application area for the nano research. Clearly the majority of the interviewed nano researchers had not or only vaguely considered the possible environmental applications or the implications of their nano research.
The relationship between nano and environmental issues is seen as quite weak by the nano researchers. "On the face of it there is only little overlap between environmental issues and what we do. Our work is very medico-oriented", (iNANO researcher).

Another iNANO researcher points to the lacking connections:
"I do not think the linkage is very strong. I have been in biology for many years and I have regarded the Ministry of the Environment as a closed system. It hasn't been a part of my world. They have had their own agenda and have run this internally and financed their own institutions through all kinds of small technology programmes. For that reason my thoughts on the environment have not been directed towards that part of the environmental world. Of course it has been part of the overall perspective, and an extra bonus, to make something environmentally friendly, but we have not directed our research towards the interaction with environmental companies or the ministry, or anything like that".

The linkage between environmental researchers and the environmental industry and nano researchers is also quite weak; seemingly there is a lack of attention both ways: "The group of nano researchers is made up by molecular biologists, physicists and chemists. I think that the people who really work with environmental issues, e.g. waste water, have no knowledge of nanotechnology. That means that they can not see the opportunities in this technology. At some point when we get the nano ball rolling they too will hear about nanotechnology, and I think the opportunities of cooperation will turn up at that point", (Professor Besenbacher, Head of iNANO).
An employee at the company Alfa Laval (producing various membranes for handling pollutants), state that they do some nanotechnology, but they just don't call it that. They are interested in nanotechnology but have limited contact with the Danish nano researchers, but follow biotech research more closely.

Professor Besenbacher, Head of iNANO, emphasizes the importance of maintaining a good nano image: "When we start a new project the first thing we say is not: 'Now we are going to find a nano project which also has an environmental aspect'. It does not work that way. On the other hand, as we discussed the opportunities for the biosensor and oestrogen projects [directed towards curing cancer and hormone disturbances], I think I said that these themes were brilliant, because if we were to succeed with the projects there is no doubt that they would give us considerable PR. It would be something everybody can relate to."

For many catalysis researchers the situation is quite different. They see a close linkage to environmental issues. For example, Ib Chorkendorff, Head of the

ICAT (catalysis) center, Nano•DTU, sees the environmental aspects of his catalysis research as a clear advantage. “We seek solutions in technologies and the environmental area is an area where every body would like to see improvements. In that way we are also opportunists. You have to find funding where it is which is easier than if we researched an area without national industry and national interests.”

The very strong Danish competencies on environmental issues generally and the strong competencies in catalysis might make us expect that Danish nano researchers were attentive to environmental issues and were working more broadly with these. But that is not the case. In fact there are only a handful of Danish nano researchers whose research aim specifically at environmental issues, outside the heterogen catalysis and energy production. These researchers are typically in the periphery of the Danish nano research environment, i.e. not within the big new nano centres and mostly only working with nano science to a limited degree. They are situated at institutes working with environmental issues or areas related to this (the agricultural university, the building institute at the Technical University), where they to some extent apply nano science and nanotechnology in their research. There is a niche though at the Geological Institute, University of Copenhagen University of Copenhagen, where a small group at the NanoGeoScience Center works on environmental nano research, particularly on waste and clean water issues. These have links to environmental researchers at the agricultural university and the Technical University but only weak links to the Copenhagen Nano-Science Center.

There are some nano researchers who do some (minor) environmental projects as a part of their research. And then there is a large group, in fact a great amount of the research undertaken, whose research could have some or even major environmental impact, but where this is not the focus or driver of the research undertaken. E.g. research into new lighter, stronger, or less energy demanding materials, or research into self-cleaning or anti-fouling surfaces, research into detection of harmful substances. Section 5 on identified eco-opportunities will highlight these further.

To some degree these researcher recognize the environmental potential of their research but mostly very vaguely and typically as something they are not used to consider. E.g. a researcher of composite nanopolymers which are very light strong materials which could replace e.g. energy demanding or rare metals) state that he has a very pragmatic approach to his research and does not really know anything about the environmental potential (researcher at Aalborg University).

There are no specific environmental nano research programs (again excluding heterogenic catalysis). There is no research which aims specifically to substitute harzardous, rare or energy intensive materials. Or to build long lasting products (self-repairing, anti-corrosive, hard etc. Or to reduce resource consumption (through minituarization, targeted resource use and efficient chemical processes). All issues which are highlighted as environmental potentials of nanotechnology as discussed earlier.

The lack of environmental orientation also showed itself in the problem experienced during the foresight project in findings speakers able and willing to talk about eco-opportunities related to nanotechnology for the innovation workshops and conference planned. Obvious candidates were difficult to find and many nano researchers were hesitant of the environmental topic.

The general crude picture on green attention and search rules from the Danish investigation is that researchers at DTU, the agricultural university and Risoe are more environmentally oriented than at the pure and more basic research universities Copenhagen, Århus, Aalborg and the University of Southern Denmark. In the former the medico orientation is less strong and the search space is broader. Also, at the DTU, there are strong competencies on environmental issues and technologies, in part in some of the institutes dealing with nano research (the Center for Sustainable and Green Chemistry at the Department of Chemistry,and Department of Manufacturing Engineeering and Management, IPL). These are both part of Nano•DTU which to some degree facilitate a cooperation between the technical environmental researchers and the nano researchers here. There are, however, apart from this limited links to other core environmental researchers and the nano researchers here. Risoe has a formal key research focus en renewable energy technologies meaning that an environmental agenda is somewhat present.

All in all it seems that links between policy makers, researchers and industry in the environmental area and the new main nano research centres generally are weak.

5.4.5 Environmental search rules and risks

Generally, most Danish nano researchers are concerned about the potential environmental risks related to nanotechnology. Concerns are predominantly directed towards and restricted to the possible toxicological effects of nano particles. There is clearly a concern that public attitude towards nano may become negative as in the case of GMOs, and that it is necessary to safeguard the reputation of nanotechnology.

A few researchers also point to a possible waste and recycling problem from nanotechnology. For example, a researcher from iNANO states:
"You put a lot of technology into a range of small things, and there may be a problem in collecting and recycling them again, like with rechargeable batteries. With nano products you can not see if there is anything dangerous in the pen when you throw it in the bin; you do not know what you are holding in your hand."

The concerns of the Danish nano researchers are in line with recent international studies on nano environmental risks as discussed in section 5.3. It seems that the risk concerns are of quite new date or at least have been strengthened recently, partly because of the rising international debate following recent research projects, going into more depth with the risk aspects than has been the case before. But it also seems that the recent general Danish nano foresight report, which included risk aspects, has been an eye-opener to many Danish nano researchers when it comes to risks issues related to nanotechnology. In fact that is one of the main conclusions of the foresight report. Before, the majority of the nano researchers had not been concerned with or considered risk aspects of nanotechnology (Ministeriet for Videnskab, Teknologi og Udvikling, 2004). A few nano researchers still state that they see no environmental risks associated with nanotechnology, but that there are some ethical issues to consider.

Even though risk aspects are quite recognized, little attention is generally paid to the question of how green/clean nano production is or could become, i.e. green search rules are lacking or are insufficient. Quite many of the nano researchers interviewed lack competencies on environmental issues. They had difficulty discussing environmental issues in a systematic way and relating it to the product cycle, i.e. discussing the resource and energy use, toxicity, waste and recycling aspects related to their nano research. For example, a researcher at the Copenhagen Nano-Science Center states: "Organic electronics is a huge area in rapid development and Denmark should get going here. But if it has got something to do with the environment…I don't know if computers pollute?… An organic computer becomes CO2 and water. I guess computers belong at the bottom of environmentally pressing problems?"

All in all there are no implications that the rise of nano science with its more transdisciplinary search rules nurtures any environmental orientation or competence building so far.

At Haldor Topsøe things are quite different. Keeping up a strong green profile is important to their competitiveness nowadays. They keep a close eye on developments in environmental regulation globally, especially on chemicals, both for spotting market opportunities for their environmental catalysts, but also to handle the chemicals they use themselves properly. Their production is nowadays quite clean, they have e.g. a closed water circuit, but this has nothing to do with nanotechnology. They use hardly any catalysts in their production themselves.[17]

There has been no Danish research into environmental impacts of nanotechnology. An iNANO researcher points to the problem of timing the societal concerns and dialogues: "It is difficult to research [in risks] because we have not defined the problems yet. We are all in the process of developing nanotechnology, and if it turns out that there are environmental consequences we must look into that;, but it is difficult to start looking into things until you know what the problem is." Similarly, Professor Besenbacher, Head of iNANO, states: "I am more in line with the American way, and say, OK we do this fundamental research and when it is done we draw a line in the sand and ask: what then, are there any side effects?… We need to investigate further the toxicological effects of especially the nanotubes which may be dangerous. Today we don't have sufficient scientific evidence to say whether it is dangerous or not. And that needs to be looked into just as you do with heavy metals in paint…The day you see a problem you have to direct regulation towards it. But I can't relate to an attitude saying that something as a starting point is a problem."

The committee behind the recently finished Danish nano foresight report held a small hearing with a group of citizens about their expectations and fears related to nanotechnology (Ministeriet for Videnskab, teknologi og udvikling, 2004).The main conclusions were that there is a desire among the public that nanotechnology should be used for purposes that give benefits with due regard for people and the environment. Examples include pollution control, climate change, poverty in developing countries, and disease. The responsibility for possible adverse consequences of nanotechnology and the applicable legislation for handling them must be precise and visible. It is important that applications that are evidently dangerous should be halted or subjected to regulation with strict toxicological control in order to maintain

[17] Interview with Frederik Søby and Søren Brun Hansen, Haldor Topsøe, 26/8 2004.

confidence that the widespread use of nanotechnology will not have undesirable consequences.

5.5 Danish Nano Eco-innovation potentials

This section seeks to outline the eco-innovation potentials identified by Danish nano researchers both more generally and through a number of case studies.

5.5.1 Overall identified eco-potentials

When asked about nano-related eco-innovation potentials the Danish nano researchers particularly pointed out three areas: 1) Energy production (hydrogen society), 2) catalysis as a source of gas cleaning as well as resource and energy efficient chemicals production, and 3) sensors as a source of more resource efficient production processes or products. Of the three, the energy production was by far the one which was attributed the greatest environmental impact by most of the researchers, and also the issue they knew most about.

The overall impression is that all Danish nano researchers have some kind of or even quite high green visions related to nanotechnology, but mostly at a quite general level. An iNANO researcher states: “We need to scale things down to have enough resources when the Chinese start using computers, or else everything will break down. At the nano scale all processes are faster, also the computer communication. The same goes for chemical reactions. Things become more efficient”.

Most Danish researchers thus acknowledge various eco-innovation potentials related to nanotechnology and their own nano research, although very few actually research into this.

Table 5.2 seeks in a dense form to represent a first mapping of all the eco-potentials identified by the actors in the Danish nano community. The table shows key-nanotechnologies and their eco-potentials, as well as the main Danish nano researchers and companies involved. Also the development stage and Danish competencies (the international position) of the technology/research area are shortly stated.

Large parts of the Danish nano community have participated in the making of this lists through several mailing rounds as well as being presented as background material for the three workshops held as part of this foresight report. The findings have in this way been subjected to some scrutiny within the nano community. Overall, the table represents quite rigorous data.

The list is quite long, despite the limited attention to environmental issues in the Danish nano community. It should be stressed that the table is illustrating eco-*potentials*, i.e. research that could lead to new environmental solutions, even though environmental applications may not be the target of the research. In the table these issues are sought illustrated by shortly indicating the current and potential application field of the technology. This is in some cases quite difficult since the field of application can be very broad when we are dealing with a very fundamental technology (e.g. new nano porous materials, or new synthesis of nano particles). On the other hand, it is important in a foresight exercise to seek to point also to the more long term or novel possibilities and not only those lying straight ahead or which have obvious environmental potentials seen from the way we consider environmental problems to day.

Some of the more radical or systemic environmental opportunities may well lie in the more fundamental technologies or insights from nano science that may open up for new technological development paths.

The table represents the eco-opportunities as identified by the Danish nano researchers. The claimed eco-potentials have not been subjected to great scrutiny in this project, the considerable amount of suggestions alone makes this impossible. The purpose is not to identify those innovations with the highest environmental potential, but merely to make a first scoping study of the possibilities and visions. The table may be said to illustrate the nano researchers' entrepreneurial expectations on eco-innovations. For a great part of the nano researchers participating, considering the eco-opportunities of their research was clearly a new experience. Therefore it has also been difficult for them to be very specific about the environmental potentials of which they know little. The table therefore represents an attempt at identifying the hitherto unknown/unrecognized eco-opportunities as seen broadly in the Danish nano community. In a sense this exercise has highlighted but also created new (eco-) entrepreneurial expectations, similar to the innovation workshops held during this project. The list then is a list of possible interesting eco-opportunities, not identified main solutions to specific environmental problems.

The grouping of the technologies seeks simultaneously to capture:
- different application areas
- different nanotechnologies (manufacturing techniques)
- areas of environmental interest.

Minor subtechnologies are indicated with an "-". The grouping has been made in a dialogue with the Danish nano researchers.

The table also seeks to illustrate the diversity of the nanotechnological field and the great variety in development stage between the different research areas and technologies.

It goes beyond this study to go into a discussion of all the many technologies listed, their eco-potentials and industrial potentials. A few of the examples are discussed more in depth in the case studies in the succeeding section (marked with an "*" in table 5.2).

Table 5.2.
Suggested Danish nano eco-innovation potentials – overview.

Technologies & eco-potentials	Companies[18]	Researchers[19]
Catalytic production of chemicals:		
1.Efficient production of bulk chemicals such as ethanol, ammonium, hydrogen. Innovation for still higher energy efficiency and less chemical waste. **Stage:** Large scale production, New: micro-reactors for production of hazardous chemicals in small scale may allow more targeted, efficient production.	Haldor Topsøe	Ib Chorkendorff, Nano•DTU, DTU J. Kehlet Nørskov, Nano•DTU, DTU C. Hviid Christensen, Nano•DTU, DTU F. Besenbacher og Jeppe V. Lauritsen, INANO AU Ulrich Quaade, Nano•DTU, DTU Jane Hvolbæk Larsen, Nano•DTU, DTU Ole Hansen, Nano•DTU, DTU, Mogens Mogensen, Risø *DK world leading (top 5).*
Catalytic cleaning of gases:		
2. Environmental heterogeneous catalysts for power generation, refineries, large facilities (no catalysts for small facilities made in Denmark) **Stage:** Large scale production, but more stringent environmental requirements are coming soon. New type of catalyst under development at Haldor Topsøe	Haldor Topsøe	I. Chorkendorff , Nano•DTU, DTU C.Hviid Christensen, Nano•DTU, DTU F. Besenbacher, iNANO,AU *DK world leading (top 5).*
3. Environmental catalysts for diesel cars* Heterogeneous catalysts for cleaning the fine (and toxic) particles of diesel engines. **Stage:** development stage globally with new regulation coming up,	Haldor Topsøe Storex A/S Amminex A/S	C. Hviid Christensen, Nano•DTU, DTU J. Kehlet Nørskov, Nano•DTU, DTU Ulrich Quaade, Nano•DTU, DTU Tue Johannessen, Nano•DTU, DTU Jeppe Lauritsen, iNANO, AU Søren Linderoth, Risø *DK: new area, Danish patents and new products are on the way.*
4. Electrochemical/catalytic cleaning of gases Efficient cleaning method where electricity substitutes chemistry, application of know-how from fuel cells. **Stage:** experimental, patent submitted.	Dinex Volvo	Mogens Mogensen, Risø Kent Kammer Hansen, Risø *DK unique research.*
Other separation/cleaning processes:		
5. Bioseparation - With ultrashort laser pulses one can make membranes with nanopores in any material, including polymers and metals. These can be used for bioseparation or sensors. - Combination of membrane and fermentation processes, - Bioactive polymer membranes. No research/production in ceramic membranes for water cleaning. **Stage:** Used for gas cleaning mainly, on market within 5-10 years.	Versamatrix JURAG Alfa Laval Nakskov Danisco Christian Hansen	Bo Brummerstedt Iversen, iNANO, AU C. Hviid Christensen, Nano•DTU, DTU Morten Foss, iNANO, AU Peter Kingshott, Risø Peter Vang Petersen, Risø Gunnar Jonsson, Nano•DTU, DTU, Kemiteknik *DK new area.*
6. Remediation with nanoparticles	Roskilde Amt	Susan Stipp, KU Geologi

[18] The companies are both Danish producers/developers as well as early users of nanotechnology. Companies in brackets implies a minor contact. A few foreign companies are mentioned when they have been in a dialogue with Danish nano researchers.
[19] Researchers are from Danish Universities and Research Institutions

Immobilisation and breakdown of pollutants. - Decontamination by reaction with functional nanoparticles or thin films - either using synthetic material or modified minerals. - combined with sensors in eg. the soil - biological adhesion on natural materials and implications for degradation -"Natural antenuation": exploit the natural cleaning capacity of nanosize (clay and other minerals) particles in the soil. Applic: In soil and water, water treatment facilities, waste treatment plants and storage areas, flue gas and fly ash treatment, nuclear waste repositories, ect.. **Stage:** various – some projects improve existing commercial technology, others study the fundamental properties to develop new approaches.	Hedeselskabet SKB - Svensk Kärnebräslehantering	H.C.Bruun Hansen, KVL C. Bender Koch, KVL. K.J. Jørgensen, KVL H. Lindgreen, GEUS (C. Suhr Jacobsen, GEUS, F. Larsen, DTU & T. Christensen, DTU- environmental researchers with nano links) A. Bennow, KVL D. Plackett, Risø *DK: some projects are state-of-the-art, leading on international fronts.*
7. Controlled release into soil Controlled release of adsorbed components from nanoparticles or films. Applic: - pesticides or plant nutrient or growth regulator release from soil, sediment. Aim to improve resource efficiency and control release. **Stage:** various		Susan Stipp, KU Geologi H.C.Bruun Hansen, KVL *DK: ?*
Polymer electronics/photonics:		
8. Polymer based electronics with less use of materials, and often less energy consumption. - TFT flat screen - Local Area Networks (LAN) - Molecular computing - RFID devices **Stage:** Polymer electronics is beginning to be developed commercially, currently products are too unstable. Many applications expected in a long time horizon. Specific photonic applications are moving into development stage.	Capres Atomistix SMB/MMP BioNanoPhotonics	M. Meedom Nielsen, Risø Frederik Krebs, Risø T. Bjørnholm, KU Jan. O. Jeppesen, SDU *DK: Early stage for the time being a minor role, development in foreign countries: UK,USA, Asia, Phillips, Panasonic.*
9. LEDs * - Light emitting diodes with low energy consumption compared to incandescent bulps and no environmentally harmful substances. **Stage:** rapidly increasing performance of LED devices and expanding market globally.	RGB Lamps Nordlux Louis Poulsen Lighting Asger BC Lys NESA	Paul Michael Petersen, Risø Carsten Dam-Hansen, Risø Birgitte Thestrup, Risø Henrik Pedersen, Risø *DK: development and test of high –end innovative applications of new LEDs.*
Monitoring & diagnosis:		
10. Lab on a chip Integrated and miniaturized systems for chemical analysis on a single chip. Measure at the nanoscale. Polymer based fluid systems, photonics and electronics. Allows for decentralized, concentrated monitoring and diagnostics and thereby "early warning". - Pesticide analysis in drinking water (antibody based) detection "lab on a chip" through quantitative, competitive microarray immunoassay. **Stage:** Chips for DNA analysis are well developed and applied (but are not quite lab on a chip). Mainly products within point-of-care in healthcare. Early	Danfoss Analytical Exicon Novo Sophion T-Celic SMB SMB/MMP Danfoss Grundfos Coloplast	Pieter Telleman, MIC, Nano•DTU, DTU Leif Højslet Christensen, TI Knud Jørgen Jensen, KVL *Pesticide*: Jens Aamand, GEUS Leif Bruun, SSI Pieter Telleman, MIC, Nano•DTU, DTU *DK: Research and Commercial production.*

production in food and environment.		
11. "Pervasive sensoring" - Small cheap micro- and nano structured sensors embodied in many different types of 'devices'. (closely linked to regulation.) - Sensors based on RFID technology (tags for labelling) are expected to be largely disseminated. They are cheap, wireless and without internal energy supply (battery). The devices are disposable. Potentials for intelligent dosage systems (demand driven) & improved process control, e.g. combustion system in cars, dosage of fertilizers, washing machines, tags for waste separation (recycling) and discovering of materials… Application mainly health, automation, **Stage:** Production of condition monitoring and structural health monitoring is increasing strongly. The durability of some products is short.	Danfoss Tempress H.F. Jensen Grundfos Unisense Unisensor Foss Analytics Dantec MEMSFLOW Unisense	Aric Menon, MIC/DTU Jörg Kutter & Jörg Hübner MIC, DTU Lars Lading, STC Steen Hanson, Risø M. Meedom Nielsen, Risø "Emballage & Transport" at TI are establishing a RFID test centre. *DK: New area.*
12. Bio sensors Monitors the presence of biochemical substances. The specification is achieved via a bio-chemical reaction. The devices are very small, sensitive and potentially cheap. The physical reading can be electrical, electro mechanical, optical or ultrasonic. - Cellular sensor – the molecule changes its shape by binding - In-vivo nano sensors - Oestrogen receptors for detecting hormone-like compounds in the environment Application: mainly health, also food and environment **Stage:** Many proof-of-principle but still few commercial products. More robust sensors for routine measurements under development.	Chempaq Unisense Atonomics Vir Biosensors Radiometer DELTA Cantion, Sophion Danfoss Danfoss Bionics BioNanoPhotonics	Pieter Telleman, Nano•DTU, MIC, DTU Anja Boisen, Nano•DTU, MIC, DTU Erik V. Thomsen MIC, DTU T. Bjørnholm, KU & Tue Schwartz, Panum Jesper Wengel, SDU Jan. O. Jeppesen, SDU Steffen B. Petersen, AAU F. Besenbacher, iNANO AU Jørgen Kjems, iNANO,AU Jens Stougaard, AU N. Peter Revsbech, iNANO,AU Peter Andreasen, iNANO, AU L. Højslet Christensen, TI M. Palmgren, A. Schulz, A. Fuglsang, Knud J. Jensen, KVL Lars Lading, STC Niels Bent Larsen, Risø A. Scharff Poulsen, Risø K. Almdal, Risø *DK: research medium.*
Functional surfaces:		
13. Nano crystalline coatings Superhard nanocrystalline oxide or metal coatings with large thermal and chemical resistance **Stage:** Under development	Grundfos SCF Technologies	Jørgen Bøttiger (iNANO, AU) Ryzard Pyrz (iNANO, AAU) Bo Brummerstedt Iversen (iNANO, AU) *DK: research in front.*
14. Multifunctional nanocoatings PLD (Pulsed laser deposition) is used to produce high quality films of nm-thickness. These are oxides and metal coatings with special electrical, magnetic and optical properties, e.g. for optical communication, sensor devices and SOFC (solid oxide fuel cells). **Stage:** Experimental prototype nano-film systems, allows for fast production but currently too expensive for wider commercial use.		Jørgen Schou, Risø Nini Pryds, Risø *DK: Using new PLD equipment among European top ten.*
15. Coating surfaces with nanoparticles* - Anti-fouling, self cleaning surfaces, antibacterial surfaces Application: mainly food and medico, some environmental, wide brainstorming stage concerning applications.	B&O (nano ph.d.) Grundfos Danfoss LEGO Danisco Mærsk	Per Møller, Nano•DTU, DTU Jens Ulstrup, Nano•DTU, DTU F. Besenbacher, iNANO,AU Thomas Zwieg, TI Peter Kingshott, Risø

E.g. environmentally friendly paint for ships, anti graffiti (avoid chemical usage for cleaning), self-cleaning windows (not DK) - Self-lubricating surfaces with reduced wear and tear, reducing problems with lubricants in industrial production . Potential for water/waste water, but no research in DK. **Stage:** early production, larger production expected within 10-15 years.	Hempel	Peter Bøggild MIC, Nano•DTU, DTU Hans Nørgaard Hansen, Nano•DTU, DTU Kim Dam-Johansen, DTU Jan Lorenzen, TI *DK: close to front.*
16. Surfaces functionalized with complex carbon hydrates -biocompatible surfaces, at present for medico technological applications -glyco-chip to gene discovery, enzyme- and antibody screening **Stage**: ?	Danisco A/S Poalis A/S	Peter Ulvskuv (DIAS), KVL H. Vibe Scheller, A. Blennow ,S. B. Engelsen, B. Lindberg Møller, KVL Knud Jørgen Jensen KVL Morten Foss & Flemming Besenbacher, iNANO AU Leif Højslet DTI Bill Willats KU *DK: ?,*
17. Chemical modification of surfaces - Plasma treatment e.g. corrosion, biocompatible surfaces –(implants), adhesion, - Anti-fouling & antibacterial surfaces -Immobilized peptides, proteins, enzymes -Chemical synthesis of complex, bio-active molecules. - Coating with biolayers Applications: consumer goods, automotive, health care **Stage**: Established industry. New coatings w. functionalized polymers, e.g. switchable coatings expected time horizon 10-15 years to market.	SMB Nanon Coloplast	Anja Boisen & Martin Dufva MIC, Nano•DTU, DTU Morten Foss og Flemming Besenbacher, iNANO AU Niels Bent Larsen, Risø Peter Kingshott, Risø Jørgen Schou, Risø C. Hviid Christensen, DTU Naseem Theilgaard, TI Knud Jørgen Jensen, KVL *DK: Medium level, many research activities in Denmark.*
18. Physical modification of surfaces Achieve strong surfaces (thermic stable, wearability), & anti-fouling properties. - Nanoporous membranes with selective permeability to short-chained carboxylic acid. Can be used for control of biogas plants, monitoring of fermentation in biotechnology. - Laser treatment - Replication of nano structures in metals and polymers. - Produce membranes (see bioseparation). **Stage:** patents with external partners, on its way to be accepted by industry (food & medico). Within 2-5 years larger market is expected.	Lego Glud & Marstrand Radiometer	Morten Foss, iNANO,AU Peter Balling, iNANO, AU Keld West, Risø Niels Bent Larsen, Risø Hans Nørgaard Hansen, Nano•DTU, DTU Anders Kristensen MIC, Nano•DTU, DTU Leif Højslet, TI Torben M. Hansen, TI, *DK close to front.*
19. New Liquid Crystal Smart Window Window for solar and daylight control applications, based on films of polymer-/liquid crystal composites. Allows for higher energy efficiency though 3 operating modes: selective reflective (limiting overheating), transparent, and scattering. Fast response times independent of the glazing surface. **Stage:** prototypes, estimated 5-7 years to market	European companies, no Danish companies	Karsten I. Jensen, Nano•DTU, BYG, DTU Finn H. Kristiansen, BYG.DTU Jørgen M. Schultz, BYG.DTU *DK: research into the metrology as part of EU project.*
20. Intelligent windows/signs/boards Coatings (with electro chromes) opens/shuts for the sun or change colour, allows for better energy efficiency.	Velfac	Mogens Mogensen, Risø Keld West, Risø *DK: early stage research, only*

Stage: Development of energy saving building components.		*little activity.*
21. Natural anti-fouling Use natural antibacterial agents for surface modification. Potentially save chemicals and water for cleaning or for producing other coatings. **Stage:** very early/infant, but not so far from market (5-10 years)	SMB	Peter Kingshott, Risø Lone Gram, Institute for Fisheries. *DK among pioneers, also few other places, e.g. Australia.*
Composite materials: One of the two components contains structural modifications on nanoscale.		
22. Fibre reinforced polymers - Plant fibres with nano-structured surfaces for improved interfaces in composites. - Polymer nanofibres (self-assembled and self-reinforced). - Nanocomponents as sensors in composites. Eco-potential in light, thin, strong materials e g. substitute glass fibre, steel and other metals, save energy use in transport. **Stage:** long-term, 10-20 years to market.	NKT Flexibles Vestas NEG Micron LM Glasfiber	Anne Belinda Thomsen, Risø Bent F. Sørensen, Risø Bo Madsen, Risø Hans Lilholt,Risø Peter Kingshott, Risø Henrik Myhre Jensen, AAU R. Pyrz, AAU Anja Boisen MIC, Nano•DTU, DTU Karsten Jakobsen, Nano•DTU, DTU Robert Feidenhans´l, KU *DK: in front.*
23. Super Insulating Aerogel Windows Nano structured monolithic silica aerogel used as transparent insulation material in windows. Good optical and thermal properties of aerogel allows for windows with both high insulation and high transmittance. **Stage:** prototypes, estimated time to market is 5-7 years.	European (e.g. Airglass, Sweden) (SCT Technologies)	Karsten I. Jensen, BYG.DTU Jørgen M. Schultz, BYG.DTU Finn H. Kristiansen, BYG.DTU *DK: Unique expertise in handling monolithic silica aerogel.*
24. Bioplast Polymer materials based on organic materials, permeability changes by addition of nano composites. Use of (nano) clay particles, sometimes in modified form. Is degradable, replaces fossil fuel resources of conventional plast. **Stage:** early, some products are in production, but short durability. For bulk (packaging) as well as refined products	Arla Foods	David Plackett, Risø Vibeke Holm, KVL (ph.d.) Peter Ulvskov (DIAS), KVL H. Vibe Scheller, A. Blennow, S. Balling Engelsen (KVL) *DK: new nano research area.*
Nanoporous materials:		
25. Zeolites Development of organic/inorganic networks, metalphosphate lattice structure zeolites. Used for catalysis, gas storage, gas separation, chemical synthesis. **Stage:** Development. Zeolites are used in large quantities industrially. See also "Gas storage"		Bo Brummerstedt Iversen, iNANO, AU Torben R. Jensen, iNANO, AU Jens E. Jørgensen, iNANO, AU Henrik Birkedal, iNANO, AU Hanne Lauritzen,TI Claus Hviid Christensen, Nano•DTU, DTU *DK: Research in front.*
26. Thermoelectric materials For cooling or energy production based on host/guest materials with nanovoids. **Stage:** Used today by NASA. New breakthrough may change cooling and/or energy conversion in a fundamental way.	Danfoss Grundfos SCF Technologies	Bo Brummerstedt Iversen, iNANO, AU Lasse Rosendahl, Energiteknik, AAU Georg Madsen, Kemi, AU *DK:Research in front.*
27. Nanoporous polymer materials Via self organisation at nano scala and corrosion creating a unique homogenous cavity structure. Application: potentially wide, e.g. membranes, electro osmotic pumps, controlled release and diagnosis. **Stage:** early experimentally		Sokol Ndoni, Risø Martin E. Vigild, Nano•DTU, DTU *DK: among pioneers, also 4-5 places in USA, Japan.*

28. Super vacuum insulation Coal doped nano structured aerogel used as spacers for vacuum insulation panels. Application: in refrigerators, freezers, coolers, as building insulation etc. Other applications of aerogel: - Substrate for catalytic materials, - Gas filters, - Waste encapsulation and membranes, etc. **Stage:** vision/possible project idea and reasonable price.		Karsten I. Jensen, Nano•DTU, BYG. DTU Jørgen M. Schultz, BYG.DTU Finn H. Kristiansen, BYG.DTU *DK new area, participates in EU project.*
29. Ceramic insolation Ceramic nanoporous tiles (ceramic processing) for high insolation capacity. **Stage:** expensive, used in Space shuttles, vision/potential research idea.		Mogens Mogensen, Risø *DK no research so far.*
Nano particulate & nanofibrous materials:		
30. Nano particles formed into meshes, wires or colloid 3D constructs. Aimed at medico (transport & penetration, increase surface area) but wide application potential, e.g. as scavengers of pollutants, flocculation... **Stage:** Experimental		Sokol Ndoni, Risø T. Bjørnholm, KU Peter Kingshott, Risø Keld West, Risø B. Lindberg Møller, KVL *DK among early pioneers.*
31. Supercritical fluids Synthesis of nanoparticles in any form and shape, e.g. TiO_2, ZrO_2, Al_2O_3, Fe_2O_3. Green synthesis without using organic solvents. Extraction processes: conversion of slurry to H_2 and CH_4. **Stage:** Commercially available today	Grundfos SCF Technologies	Bo Brummerstedt Iversen, iNANO, AU Torben R. Jensen, iNANO, AU Jens E. Jørgensen, iNANO, AU *DK: New area.*
32. Synthesis of nanoparticles * Hydrothermal and supercritical synthesis of e.g. complex oxides, magnetic particles etc. for much faster and more energy efficient synthesis of nanoparticles. **Stage:** Used commercially today (fuel cells, solar cells, catalyst supports, electronics etc). An improvement of size distribution and price may create a burst in commercial exploitation.	Grundfos SCF Technologies	Bo Brummerstedt Iversen, iNANO, AU Torben R. Jensen, iNANO, AU Jens E. Jørgensen, iNANO, AU Henrik Birkedal, iNANO, AU C. Hviid Christensen, DTU *DK: New research and production area with promising new unique production facility.*
33. Biomimetic materials Develop new materials based on the study of fundamental mechanisms of biomineralisation. **Stage:**?.		Susan Stipp, KU Geology Karen Henriksen, KU Geology (ph.d. student) *DK?.*
Energy production:		
34. Energy conversion Micro/nanostructured fuel injectors for combustion engines. Injectors manufactured using ultrashort laser pulses enables improved atomization, which ensures improved combustion of e.g. diesel. **Stage:**?.	Bosch GmbH	Peter Balling, iNANO, AU *DK: New area.*
35. Hydrogen production & fuel cells/bio fuels - Hydrogen production - Hydrogen storage in nanoporous materials (metal hydrides) - Cheap materials for electrodes (nano structured) **Stage:** early production	Haldor Topsøe IRD Fuelcells	J. Kehlet Nørskov, Nano•DTU, DTU I. Chorkendorff, Nano•DTU, DTU C. Hviid Christensen, Nano•DTU, DTU Mogens Mogensen, Risø Søren Linderoth, Risø R. Feidenhans'l, KU F. Besenbacher, iNANO, AU Frank Elefsen, TI, *DK: New area but approaching*

		international front.
36. Gas storage Synthesis of complex metal hydrides promising for H_2 storage and thus hydrogen fuel and nanoporous organic networks. **Stage:** Early development		Torben R. Jensen, iNANO, AU Bo Brummerstedt Iversen, iNANO, AU Jens E. Jørgensen, iNANO, AU C. Hviid Christensen, Nano•DTU, DTU *DK: New area.*
37. Polymer solar cells Very cheap solar cells printed on thin plastic films, potential for wide distribution of solar cells, e.g. integrated in products. **Stage:** experimental, short durability, first products expected soon.	Siemens	Frederik Krebs, Risø *DK: New area.*
38. CO_2 sequestration Development of risk assessment models for storage of CO_2 in exhausted oil/gas reservoirs. Based on study of fundamental nano level processes for mineral-gas and mineral-liquid-gas interaction. **Stage:** ?		Susan Stipp, KU Geology *DK: New area, project with European partners.*
Atmospheric research:		
39. Nano science research into ozone layer and global heating. **Stage:** Probably not technically relevant		Ole John Nielsen & Merete Bilde, KU

5.5.2 Eco-potential qualification

The main conclusion of table 5.2 is that Danish nano researchers identify a very wide range of eco-potentials connected to key nano research areas. Many of these potentials have also been pointed to in previous studies and workshops, compare the discussion in section 5.3 on international findings. But table 5.2 offers a more comprehensive list with more details related to concrete research areas and technologies than has been carried out before. It should be remembered that the list reflects the Danish identified potentials and refer to Danish nano competencies only. In other countries the picture may look different. There is e.g. no photocatalytic research for water cleaning in Denmark, which is often highlighted as one of the big eco-potentials of nanotechnology.

The technologies pointed to overall indicate that there are some intrinsic features of nanotechnologies that may facilitate eco-innovation within a wide diversity of nanotechnologies, as others also have argued, compare section 5.3. The table operates with eleven different main research /technology areas and identifies in all 39 research areas/technologies which could offer eco-potentials. These can be further grouped into four main groups, representing different ways of contributing with environmental benefits: The table illustrates numerous examples of how nanotechnologies imply new opportunities for making more tailor-made, targeted, sensitive, integrated and intelligent products, in short *smart tailored products*. Combined with the opportunities nanotechnology offers for making completely *new materials*, which are thinner, lighter and stronger or possess new properties, nanotechnology may well provide a platform for a more resource efficient economy. Finally *energy production* must be mentioned as the third area and improved *environmental remediation and cleaning* as the fourth area where nanotechnologies may have considerable positive environmental impacts. These will be discussed further below.

This is not to say that the mentioned nanotechnologies are resource efficient per se and will solve the environmental problems if widely developed. The environmental benefits depend very much on how the technologies are being applied and how they feed into and possibly affect overall consumption patterns. Currently most of these research areas and technologies are not being developed with environmental benefits in mind in Denmark so the eco-potential may not be explored. Lacking knowledge especially of the research areas at the early stages of development means that the specific environmental benefits are difficult to assess particularly considering the broad application area of most nanotechnologies.. Because nanotechnologies are enabling technologies many of the environmental effects will be widespread but of a more indirect character. They will often be integrated in (and thereby change the properties of) other products and materials and their effect must be seen in combination with these. In the following the eco-potentials will be discussed more in depth, referring to the box numbers of the table above.

5.5.2.1 Smart tailored products

The eco-potential of smart tailored products relate, roughly speaking, to the research areas:

- Functional surfaces (making strong, self-repairing, anti-fouling, self-lubricating, bio-compatible, energy preserving/producing, selective surfaces).
- Catalytic efficient production of chemicals (less energy and waste)
- Polymer electronics/photonics (particularly less energy)
- Monitoring and diagnostics (e.g. pervasive highly sensitive sensoring and tags – based on cheap, disposable, organic electronics and biosensors).

Alone *functional surfaces* are represented by nine very different technologies, some at a commercial stage, some very experimental. Quite many Danish nano researchers are occupied here in this very fundamental nano science discipline, where Denmark possesses quite strong competencies. Company involvement is, however, somewhat limited so far. The eco-potentials are considerable because of the potential widespread application, and varied though application today is primarily medico oriented. There are a few examples of current commercial environmental applications with self lubricating surfaces used in industrial production saving resources (see no.15), energy efficient windows through nano coatings (see no. 19 and 20) as well as three examples leading to less chemical and water usage in the case given in the succeeding section.

Catalysis, the core Danish nanotechnological competence, leads to more resource efficient chemicals production as will be discussed further below.

Polymer electronics/photonics represent radical innovations in the for the global economy crucial electronics industry. Polymer electronics is a small new niche in Denmark as well as globally with interesting perspectives and some industrial activity. But considerable technical problems remain, though some commercial products exist. The eco-potentials may be considerable, because radically new types of electronic products may be developed. In most cases polymer electronics offer environmental benefits mainly in the form of energy efficiency, see noticeable the LED case below (no.9), possibly one of the nanotechnologies with the biggest immediate environmental potential.

Monitoring and diagnostics represent one of the biggest nano research areas in Denmark when it comes to numbers of researchers and it is also here we find most nano dedicated companies, primarily small start up companies. The identified technologies (pervasive sensoring with sensors and tags, lab-on-an chip and biosensors, (see no. 10-12) might facilitate continuous and real-time measurement and diagnosis of environmental parameters in a way that has not been possible before. The environmental potential of this element alone may be contested, but used in combination with other intelligent (nano) products and materials it may contribute in important ways to greater resource efficiency. The application orientation today is, however, primarily medical. There is though an example of sensors for pesticide detection (see no. 10). The environmental monitoring industry in Denmark is only beginning to take an interest in nanotechnology[20].

5.5.2.2 *New materials*

According to professor Hviid Christensen, Center for Sustainable and Green Chemistry, DTU, and among the environmentally most competent nano researchers in Denmark, the biggest eco-potential of nanotechnologies lies in the possibility of making completely new nano structured materials. All modern materials science to day is based on nano science, so in this sense the innovation potential attributed to nanotechnology is considerable[21]. The three material areas in the table are:

- Nano particulate & nanofibrous materials (eco-efficient production and materials with new proporties)
- Nano poreose materials – (potential for membranes, electroosmotic pumps, controlled release, insulation, thermoelectric materials for efficient cooling & energy production)
- Nano composites (lighter, stronger, degradable, renewable raw materials…)

The nano particulate and nanofibrous materials group illustrate some of the most fundamental nano science research and development. They feed into a great amount of nanotechnologies. Basically, the further development of many nanotechnologies depends on the advancements in the ability to and efficiency of making nanoparticles. The importance of this field underlines the necessity to look into the entire innovation food chain of nanotechnologies to enhance nano-innovation. Improved synthesis of nano particles (see no. 31 and 32) and forming nano particles into meshes, wires or colloid constructs to obtain materials with new properties (see no. 30) illustrate this point. In the section below is a case on new super critical nano particle synthesis showing considerable improvements in energy efficiency, speed and quality of the manufacturing technique compared to the hitherto practiced much slower sol-gel method. The company SCF Technologies involved is the only Danish company working with the manufacturing of nanoparticles. Also biomimetic materials (no.33) represent an interesting potential for making completely new materials mimicking the efficient production methods of nature.
Nano poreose materials similar make up a very important and fundamental element of nanotechnologies and are used in a range of nanotechnological devices. This nano research strives basically to make homogenous nanoscale holes in a material. The table illustrates 5 different ways, which gives rise to very different material properties and a wide range of application areas. The

[20] Interview with Kasper Paasch, Danfoss Analytical, 7.9.2004.
[21] Acccording to Hans Lilholt, program leader of the materials division, Risoe National Laboratory.

eco-potentials are considerable, e.g. improved membranes and better catalysis, and novel solutions for insulation, cooling and energy conversion (no. 25, 26, 27, 28 and 29). Some of these applications are commercial, others experimental and currently very costly but could have major eco-potentials if they reach commercialisation.

Within the composite materials research, the nano research related to the development of bioplast is one rare example where environmental aspects form an important part of the goals and search rules. The whole justification of bioplast is environmental issues in the search for plastic with less waste problems and based on renewable resources but using biomass. Bioplast research in Denmark is only a small niche though. Nano composite materials such as fibre reinforced polymers are generally very interesting from an environmental point of view because they make up lighter, thinner and stronger alternative materials to e.g steel and other metals to be used e.g in transport to save energy and material use as pointed to in section 5.3. This research, however, has limited environmental application today in Denmark. An exception is research and development into composites for the replacement of glasfibre in windmills, partly to develop better wings, partly to reduce the huge glasfibre waste problem of the big Danish wind mill industry.

5.5.2.3 Energy production

As mentioned the Danish nano researchers point to energy production as a core eco-potential of nanotechnologies. Certainly if alternative energy systems to fossil fuels were developed a large part of the environmental problems would be solved. The strong Danish catalysis competencies means that we have a good basis for contributing to the development of hydrogen based energy systems. Interestingly the Danish catalysts researchers have all moved into the related hydrogen fuel cell and storage research within the recent years, both at DTU, iNANO and Risoe and also at the company Haldor Topsoe. There seems to be a shared long term interest for realizing a hydrogen economy, in which the possible environmental benefits play an important role. The technical problems remain considerable, though and prospects are long term and uncertain. The catalysis case below illustrates recent innovations here. Other potentials within the energy area are improvements in energy conversion, the mentioned improved materials for wind mill wings and an interesting new niche in polymer based solar cells. The latter is an example of a nanotechnology which is at a very early experimental stage but which could have a huge innovation and eco-innovation potential if commercialization is realized. The high uncertainty as to the scope of this technology makes it very difficult currently to assess possible environmental benefits.

5.5.2.4 Environmental remediation

This area represents what professor Hans Christian Bruun Hansen, at the agricultural university calls “environmental nanotechnology”, where nanotechnology is used directly to reduce the amount of and the handling of pollutants. The techniques pointed to are catalytic efficient cleaning of gases (no.2,3,4), remediation through use of functional nanoparticles (no.6), more efficient bioseparation (no.5) through tailored membranes and controlled release of e.g. pesticides, nutrients and growth regulators into soil (less resource use and emission) (no.7). The latter shows how understandings of nano scale processes in the soil may be used to find novel environmental solutions.

The most novel suggestion is the use of functional nano particles (no.7) (synthetic particles or modified minerals) for binding and degrading pollutants in soil and water, waterworks, waste treatment facilities, nuclear waste storage areas, etc. Such technologies are to a limited degree already in use (see the case below on "Nat-nano-mats"). Here the importance of new, nanoscience based understanding (rather than devices) of vital nano scale processes in the environment are emphasised for finding optimum solutions to environmental problems and the construction of risk assessment models (according to Susan Stipp, GeoNanoScience Center at the University of Copenhagen).

The Danish core environmental competence within heterogeneous environmental catalysis distinguishes itself as a well-established technology (no.2). In the western world existing heterogeneous catalysts are already generally well applied. At Haldor Topsøe they state: "I don't think there is any material today which you cannot remove one way or the other but there are still many regions where it could take place. It is a question of the will to implement the existing processes where the problems are".[22]
At Haldor Topsøe they see the biggest remaining eco-potential in spreading the environmental catalysts to Asia, Eastern Europe and the rest of the developing world where there are rising huge markets for environmental technologies. In these regions environmental catalysts are now only limited applied. At Haldor Topsøe there are no expectations of major innovations in the environmental catalysts originating from the new more scientific (nano) understanding, but of more smooth developments with continuous increases in efficiency. The same goes for the catalysts used in chemical production where innovations leads to still less energy use and less chemical waste, compare the resource efficiency discussion above related to the smart products discussion (no.1). They are still facing challenges of linking up the traditional experiment based production at the production facilities and the nano science research of their R&D department. Upcoming stricter regulation on sulphur emissions means that major innovations in their environmental catalysts are necessary and they are working towards this.

The catalysis competencies are recently being applied in new directions (see also the hydrogen discussion in the energy paragraph). Catalyst researchers at both DTU and Haldor Topsøe are now moving into diesel cleaning where new regulation is coming up (see no.3). For Haldor Topsøe this is quite a new strategy since the mobility sector is a completely new type of market (much smaller users) for them where they are now specialized on big users. See also the diesel/hydrogen case below where Haldor Topsøe, though, is not involved. Also new research is undergoing within electrochemical cleaning of gases where electricity replaces chemicals (no.4).

The 6 case studies in the succeeding section represent examples of a more detailed discussion of both innovation opportunities and environmental impacts.

5.6 Environmental assessment - system expansion or system substitution

An important aspect to consider in the evaluation of environmental benefits and risks is whether the developing technology will meet the needs of society in a new more environmentally friendly way or whether the technology creates

[22] Interview with Frederik Søby, Haldor Topsøe, 26/8 2004.

new needs that may either reduce or increase pressure on the environment. No definite answers can be given for an emerging technology but some considerations can be given both in general and for more specific potential application areas. Here the general aspects are dealt with based on the high-priority technology areas pointed in the recently suggested Danish nano action plan (Ministeriet for Videnskab, tecknologi og udvikling 2004). These are as mentioned:
Nanomedicine and drug delivery
Biocompatible materials
Nanosensors and nanofluidics
Plastic electronics
Nano-optics and nanophotonics
Nanocatalysis, hydrogen technology, etc.
Nanomaterials with new functional properties
Nanomedicine and drug delivery is expected to be mostly a substitution.

Current deliveries of drug could be more efficient in terms of either being more specific in targeting the relevant receptors in the body or in releasing/dosing more correct amounts of medicine. Such developments could lead to a substitution of current drug delivery techniques resulting in less use of medicine and possibly less releases to the environment. It may also lead to expansion of the areas in which the medicine is used and perhaps thus to a more widespread use of the medicine.

Biocompatible materials will probably to a large extent also be substituting currently used implants in humans. Another related aspect is nano designed surfaces that inhibit or promote growth of microorganisms. Especially surfaces that inhibit growth may be used to substitute a wide array of biocidal applications.

Nanosensors and nanofluidics could be expected to cause an extension of the use of monitoring, since it may be possible to decentralise the analysis and maybe also to measure more. However, such an extension may be an environmental benefit if it enables a faster reaction and solving of problems upfront.

Plastic electronics is expected to cause a more dispersive and invasive use of electronics and will no doubt extend the use of electronics, possibly increasing the overall environmental impacts of electronics.

Nanooptics and nanophotonics have different application fields like e.g. LED, polymer displays, and microstructured fibres (for transmissions). The nanotechnology can to a wide extent substitute existing technologies for lighting and for displays, but they may also results in extension of the use of e.g. displays. Nanocatalysis, hydrogen technology etc. are expected to primarily substitute currently used technologies.

Nanomaterials with new functional properties cover a wide spectrum of materials and particles. Examples are magnetic nanoparticles used in data storage or nanoparticles absorbing specific wave lengths of light used in cosmetics. The area of application is so wide that it can be expected to both substitute existing technologies and to extend the use to new applications. Given the enabling and in most cases emerging nature of nanotechnologies they are likely to have profound effects on wide parts of the production and consumption patterns which need to be taken into consideration when assessing the overall environmental impacts of these technologies. We need to elaborate further into these issues.

5.6.1 Cases on nano eco-potentials

Based on input from a number of Danish nano researchers 6 case studies are brought here to illustrate the innovation and environmental potentials more in detail. These can be used for a more specific environmental assessment since more is known about the specific potential application areas and production techniques. A short environmental assessment is made on each case by Stig Olsen, IPU, bringing a balanced valuation of environmental benefits as well as possible threats.

The cases are chosen so that they illustrate different kind of nanotechnologies and how these may offer different types of solutions to environmental problems. They are examples of more mature nanotechnologies, i.e. there are already products on the market. Hence the cases also seek to illustrate interesting Danish innovation activities. The cases have rather clear environmental advantages but this does not mean that these are the innovations with the highest eco-potentials.

5.6.1.1 Case: Super critical synthesis of nanoparticles[23] – innovation in nano manufacturing (no.32)

Nanomaterials are cornerstones in many attempts to develop and exploit nanotechnology. Numerous new applications are being developed including electronics, sensors, coatings, optical fibres/barriers, ferro fluids, ceramics, membranes, catalysts, paints, lubricants, pesticides, food additives, anti-microbials, sunscreens, fuel cells, solar cells, cosmetics etc. In virtually all applications of nanomaterials it is the primary synthesis of the materials, which is limiting further exploitation of nanotechnologies. It is essential to focus on new processing technologies if nanomaterials are to become competitive in the market.

Supercritical synthesis processes comprise sustainable green chemistry routes as the reaction media e.g. are environmentally benign CO_2 or H_2O in the supercritical state. Compared with the present state-of-the-art in producing nanomaterials, supercritical processes allow production at significantly lower temperatures and shorter reaction times than by conventional methods, and the need for subsequent drying and/or calcination is eliminated. The supercritical preparative schemes hold great promise for revolutionizing the quality and availability (reduced cost, easier processes, improved homogeneity) of modern nanomaterials. Whereas conventional sol-gel methods may take hours, the supercritical methods are finished within less than a minute.

There have been tremendous advances in supercritical fluid technology in the last decade. Today the traditional applications in extraction processes (e.g. caffeine from coffee) have been augmented by applications e.g. in materials processing, organic reactions, separations, polymers, pharmaceuticals etc. Danish applications with environmental implications include wood treatment (the brand name "Superwood") or water treatment and conversion of organic waste to hydrogen and methane and biodiesel. Supercritical fluids exhibit unique properties such as gas-like mass transfer properties (diffusivity,

[23] Data for this case was provided by Professor Bo Brummerstedt Iversen from iNANO at Aarhus University.

viscosity and surface tension), yet having liquid-like properties such as high solvation capability and density. Furthermore, the solubility can be manipulated by simple means such as pressure and temperature.

Together with the Danish company SCF Technologies, iNANO has recently developed a unique multipurpose, continouos flow, supercritical synthesis reactor capable of producing extremely homogenous nanoparticles. The system, which can handle all common supercritical solvents, allows easy scaling to industrial production. The flexible design allows synthesis of most materials, which are otherwise fabricated by sol-gel or hydrothermal methods. The system, which can handle all common supercritical solvents, allows easy scaling to industrial production. The flexible design allows synthesis of most materials, which are otherwise fabricated by sol-gel or hydrothermal methods.

Environmental assessment
Compared to the processes normally used in nano particle production as listed in table 5.2 it can be seen that the supercritical synthesis of nanoparticles undoubtedly will present an environmental advantage compared to the hitherto traditional production methodologies, even though the alternative sol-gel process is not one of the most energy requiring processes. Considering the raw materials the supercritical synthesis may potentially be able to use raw materials which are less processed. It can be expected that there are no differences in the use and disposal stage of the nanoparticles. The most significant difference will probably exist in the processing of the nanoparticles. The super critical synthesis of nanoparticles is likely to reduce the first of all the time but also the costs, and improve the homogeneity of the nanoparticles which may lead to a larger use of nanoparticles. Depending on the properties and use of the particular nanoparticle (e.g. as shown in table 5.2) this may lead to either environmental benefits or increased risks.

5.6.1.2 Case: Nanotechnological coatings based on sol-gel synthesis[24] - innovating surfaces

A newly developed type of chemically synthesised hybrid coatings produced by means of the so-called sol-gel technology (sol like in solution and gel like in gelation), also characterised as chemical nanotechnology, has revolutionized the opportunities for altering the surface properties of a large series of material which includes nearly all metals and alloys, glass, wood etc. by the formation of a strongly connected inorganic, ceramic network combined with the organic chemistry’s possibility of introducing various functionalities.
The sol-gel technology is based on the polymerising of small inorganic molecules; in a simple instance metal alkoxides $M(OR)_n$, are being used. In these cases the metal, M, represent silicon, titanium, zirconium, aluminium etc., and R presents an alkyl group, typically methyl or ethyl. Through hydrolysis and a subsequent condensation reaction it is possible to cross-link the molecules into a metal-oxopolymer nanoparticles in dimension of 1-50 nm. These nanoparticles constitute a basis for producing thin ceramic coatings, ceramic phases or porous structures.

During the last couple of years, research and development within chemical synthesis has resulted in an overwhelming number of commercially available metal organic chemicals, which makes it possible to introduce different organic groups in covalent connection with this inorganic network. By introducing such organically modified metal alkoxides into the formation of

[24] Data for this case has been provided by Thomas Zwieg, Danish Technological Institute, Aarhus.

the before mentioned nanoparticles, the backbone of the ceramic coatings will be enriched with a chosen functionality. Hereby it will be possible to modify the physical, chemical, optical and mechanical properties of the formed coatings or structures in an extent that cannot be reached by conventional methods.

Within the last couple of years, the Danish Technological Institute has experienced a great success in producing sol-gel coatings with emphasis on specific functions, i.e. lime stone repellence on metal surfaces, ice repellent properties for application in the aircraft and wind mill industries and anti-graffiti lacquer for instance for the train industry. For the anti-lime stone and anti-ice coatings the adhesion of the respective crystals is so minimal that a slight dynamic influence – for example flow of water or air – is sufficient to clean the surface. Therefore a large saving in the application of chemical ice and lime stone removing materials can be expected. The use of chemical nanotechnology within the development of the new type of anti-graffiti makes it possible to remove graffiti vandalism on prepared surfaces with just water and not – as up to now – with the use of chemical solvents.

The experiences obtained in these projects have justified an expectation of a successful application of the sol-gel technology for the production of a non-poisonous anti-fouling coating intended for boats. With support from the Danish Ministry of the Environment, a craft project with the purpose of testing some selected sol-gel lacquers was completed in 2004. In co-operation with three yacht clubs the lacquers were applied to a number of test plates and private boats and tested throughout the yachting season. The most important results obtained from this project include a visible reduction of alga growth and a considerable easier ability to clean the boats at the end of the season.

Environmental assessment

The nanotechnological coatings described can to a wide extent be expected to substitute other ways of providing functions like de-icing, antifouling etc. Thus the development is not expected to create new needs.

De-icing is currently performed using different types of organic solvents, mostly glycols, and the use of a nanotechnological coating could be able to substitute the use of these. The same applies to anti-graffiti. It is not known, yet how much coating will be required, how long it will last and whether components of the coating will be released over time. It also remains to be seen what the possible effect of such a release could be.

Antifouling is normally performed with rather toxic compounds such as organotin compounds, which cause impacts in the marine environment, especially in the harbours. A substitution of these by non-hazardous alternatives would clearly be an environmental benefit, if the nano technological coating does not release other similarly hazardous compounds during use.

In a LCA comparison between a nanotechnological varnish and three conventional varnishes (water based, solvent based and powder) the nanotechnological varnish clearly were environmentally better in terms of the amount of material used and emissions (VOC and others) during the life cycle, partly because it was possible to obtain the same properties applying thinner layers of coating (Steinfeldt et al., 2004).

The production of nanomaterial via the sol-gel production process is not expected to be very different from other types of chemical processing.

5.6.1.3 Case: LEDs for eco-innovation in lightning[25] - high-end applications of nanotechnology

LEDs is one of the areas frequently highlighted when referring to the eco-potentials of nanotechnology[26]. Commercial Light Emitting Diodes (LEDs) are in a rapid stage of development globally. The light emission is now so strong that LEDs can be used for general illumination. The successful application of LEDs in general illumination is forecasted to provide significant economic and environmental benefits. Today LEDs can be found in many applications requiring coloured light, such as e.g. signs, traffic signals and automobile brake lights. Recent advances in nanotechnology, compound semiconductor materials and enhanced manufacturing techniques are enabling a new generation of blue, green and white LEDs. White LEDs are based on a blue LED used to pump a mixture of phosphors in order to produce white light. White LEDs can, however, also be achieved by mixing light from multiple LEDs of different colour. The latter, known as RGB-technology, is a new technology being developed in Denmark. This technology has potentially higher energy efficiency and the advantage of color tuneability leading to flexible lightning sources.

The advantages of LEDs are many, such as low maintenance cost, tuneability and compact size, but also environmentally important factors such as longevity, energy efficiency and no environmentally harmful substances. In the user phase the energy consumption is low compared to incandescent bulbs, leading to SO2 reductions etc. LEDs need only about 50 percent of the power required by a normal bulb in order to produce the same amount of light[27].The longevity in the user phase means a considerable reduced production of light sources (replacing 50-100 incandescent bulbs with low longevity). LEDs are also environmentally friendly in the waste phase, as the content of heavy metals is small, (e.g. no mercury, no UV-light) compared to fluorescent lamps. Since LEDs can now produce white high quality light, and thereby may be expected to replace the conventional lighting technology such a switch would result in substantial energy savings. Recent estimates suggest that under the U.S. Department of Energy (DOE) accelerated schedule, solid-state lighting could displace general illumination light sources such as incandescent and fluorescent lamps by 2025, decreasing energy consumption for lighting by 29 percent and saving 3.5 quadrillion BTUs[28]. In Europe, about 10 percent of the electrical power produced is used for lighting, in Denmark the figure is 12 percent.

Commercial LEDs have reached and surpassed the energy efficiency of incandescent lamps with a luminous efficacy of 60 lumens/Watt for red LEDs and approx. 20-40 lumens/Watt for white LEDs. Red LEDs have reached 100 lumens/Watt in laboratories and with future improved LED materials the luminous efficacy is expected to reach 150 lumens/Watt. Thus LEDs are expected to challenge the energy efficiency of fluorescent lamps in the future. Nanotechnology plays a major part in the development of new enhanced LEDs, with higher energy efficiency but also higher total luminous flux. (The total luminous flux from a single LED package is today so low that only low wattage incandescent lamps are readily replaced by SSL sources). Novel growth technologies using nanoscale patterning are employed for improved

[25] Data for this case is provided by Carsten Dam-Hansen and Paul Michael Petersen, Risoe National Laboratory and Jørn Scharling Holm, NESA.
[26] European Commission (2004). Nanotechnology. Innovation for tomorrow's world.
[27] European Commission (2004). Nanotechnology. Innovation for tomorrow's world.
[28] Source: http://www.sandia.gov/lighting/

substrates and precise layering of semiconductor materials. Quantum-dot heterostructure LEDs with structures sizes around 10 nm are utilized for high efficiency light generation. Nanocomposite LED die/chip encapsulants with high refractive index is being developed for improved light extraction from the LED chip. Quantum-dot structures in the encapsulant material can emit visible light when excited by a UV LED and may thus be used as nanophosphor, an alternative to using yellow phosphors for white light generation. This may result in new ways to tune the spectrum of emitted white light.

The LED technology development is taken place globally mainly driven by large companies in the US, Japan and Germany and research institutes like Sandia National Laboratories. In Denmark a niche is sought developed directed not so much towards components but towards novel high end applications of high brightness LEDs for general illumination. An ongoing project aims at developing a high quality LED lamp, based on RGB-technology, with high color rendering and tuneability for replacement of low wattage incandescent lamps. Novel micro- and nanostructured optical elements are being developed for efficient color mixing and light control. The project is a cooperation between Risoe National Laboratory and Danish industrial partners, NESA, RGB-Lamps and Nordlux. A new project starting 2005 continues and extends this work aiming to develop novel types of fixtures and lamps for this new generation of innovative and flexible forms of illumination. This is done in cooperation with Asger BC Lys and Louis Poulsen Lighting. Both projects are supported by ELFOR, Dansk Eldistribution.

Environmental assessment

Lighting is a heavy energy user, 10-12 percent of the electricity consumption, so reductions here have major environmental impacts. Since lighting is widely used both in public and private spaces it is not likely that the development of new types of lighting such as LEDs will extend the use of lighting considerably. Thus it is expected that LEDs will substitute other types of lamps rather than create new needs. In the use phase the development of LEDs that are more energy efficient will provide an environmental benefit. An incandescent lamp has an efficiency of app. 5-12 lm/W whereas it is foreseen that efficiencies of 150 lm/W may be obtained by LEDs. But already now LEDs with efficiencies of 20-60 lm/w are more efficient than incandescent lamps. However, the now widely used fluorescent lamps still have higher energy efficiencies (50-75 lm/W) than LEDs.

Looking into the materials used for producing the different types of lamp, LEDs have an advantage in comparison with fluorescent lamps since no mercury is used in LEDs. It can also be expected that the material amounts will be less for LEDs. During production of LEDs it can be expected that the energy requirements are high since nanomaterials used will probably be produced by vapour phase deposition or lithography, both processes requiring clean room facilities (see table 5.2). During the disposal fluorescent lamps are collected as hazardous waste thereby securing collection and reuse of mercury and other materials. This is not the case for incandescent lamps and probably not for LEDs. For LEDs the reuse of nanomaterials may constitute a problem.

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The future practical application of quantum dots will most certainly lead to a further increase in energy efficiency within light sources. Quantum dot technologies are anticipated to find their place in display technology, especially in combination with OLEDs (organic LEDs). It will take a few more years, however, until quantum dots reach a position as commercially viable products (Steinfeldt et al., 2004).

5.6.1.4 Case: Nat-nano-mats – Natural nano-materials for treating water, immobilising waste, or dosing pesticides and fertilisers[29] *- Innovation for environmental remediation*

Insuring clean water, dealing with our waste, and producing food are some of the most critical issues of sustainability for human existence as well as for a secure environment for plant and animal species. Often, in our attempts to solve one pollution problem, we create one or several more. Strategies that make use of natural processes on natural materials are one way of minimising adverse anthropogenic effects.

Nano-materials have been around in nature since the beginning of time. Mineral particles, macromolecules and coatings only a few atomic layers thick have always controlled the composition of water, whether in rivers, lakes and the ocean, or in soil or hydrothermal systems. Reactions at the interface between natural solids and fluids have always been responsible for uptake and release of trace components that can be essential for life or that can be toxic. With the birth of nanotechnology, tools became available that provide geoscientists direct observation of these processes so their work has entered a new realm. There are three aspects of ‘nano’ – nano-metrology (the development of instruments and methods for observing samples), nano-science (the definition of physical and chemical processes at the nanometer-scale), and nano-technology (the development of devices and advanced materials for solving specific problems). The development of a saleable product, including those relevant for environmental protection, requires progression in that order. The application of nano-techniques to environmental questions is still in its infancy, but a good start has been made. There is a group of researchers[30], who have been working loosely together many years on defining the properties and reactivity of nanoparticles in an environmental context – to develop and maintain safe water supply, to immobilise or treat waste, and to optimise dosage of pesticides and fertilisers. There have been projects over the past 20 year, that have applied spectroscopies sensitive to the top 10 nm of solids and the past 15 years using nano-scale microscopies, where the goal has been to define the mechanisms of uptake, release and degradation.

[29] Data for this case has been provided by Susan L. Svane Stipp, NanoGeoScience Group, Geological Institute, University of Copenhagen, Hans Christian Bruun Hansen and Christian Bender Koch, Environmental Chemistry Group, Department of Natural Sciences, KVL

[30] Susan L. Svane Stipp, NanoGeoScience Group, Geological Institute, University of Copenhagen, Hans Christian Bruun Hansen and Christian Bender Koch, Environmental Chemistry Group, Department of Natural Sciences, KVL, Thomas H. Christensen, Erik Arvin and Hans-Jørgen Albrechtsen, Environment and Resources, DTU.

Here are case studies based on three natural nanoparticulate minerals that are common in rocks, soils and sediments, as well as water supply systems. These materials are stable and safe. They are calcite, $CaCO_3$, iron-oxides/hydroxides and alumino-silicates. There are many other minerals with interesting potential, but these three demonstrate the range of problems that natural materials can and will be able to solve with help from nano-technology.

The pollutants and beneficial components that interest us, that can move or not move in the environment, take many forms. Pollutants can be: i) inorganic, including heavy metals such as lead, arsenic, cadmium, nickel, etc.; ii) organic, such as pesticides, halogenated hydrocarbons (solvents, dry cleaning fluids), spilled oil, drugs, etc.; iii) radioactive, such as hospital and research waste, and spent fuel rods stored by Denmark's neighbours; and biological, such as viruses and bacteria that may be pathogens themselves or that produce unwanted compounds. Those that are beneficial include: inorganic and organic components necessary for plant and animal growth and micro-organisms that help degrade toxic materials to harmless ones or release beneficial compounds.

a) Nano-materials in Water Treatment

Most municipal water supplies tap reservoirs in chalk or in glacial till where chalk is a component. Some heavy metals, such as arsenic and nickel, are released to groundwater when pyrite in the chalk oxidises. Chalk is often more than 90% calcite ($CaCO_3$) and this mineral is interesting because of its open atomic arrangement, which allows easy uptake of toxic metals such as Ni^{2+}, Cd^{2+}, Pb^{2+} onto surfaces and into particles. Thus, groundwater at equilibrium with chalk has a built-in potential for self-treatment. A recent study (Roskilde Amt, Hedeselskabet and NanoGeoScience, Geological Institute, Copenhagen University) has shown that the very fine, biogenic chalk particles remove nickel much more effectively than pure calcite with the same surface area. Biomineralisation experiments with the nanometer-scale elements of coccoliths, one of the components of chalk, are currently underway at NanoGeoScience, Copenhagen University to define the parameters responsible for the enhanced uptake and to produce nano-particles that improve on the natural material. This is an innovation with exciting possibilities. It takes a successful bulk technology and redefines it with nano-scale materials.

When fresh groundwater is pumped from a well, it is aerated, usually by splashing over a series of concrete steps. H_2S (smell of rotten eggs) bubbles out and O_2 enters, dissolved Fe(II) oxidises and nanoparticles of Fe-hydroxide (rust) precipitate. The flexibility of the iron oxide structure, their very high surface area, and their reactivity result in removal of many heavy metals and organic components in a completely natural process and one that is of great benefit to the water suppliers. However, costs can be reduced and safe drinking water production can be optimised by developing and stabilising even smaller particles, and more important, altering their properties to optimise immobilisation capacity. Research at DTU ER, KVL IGV and KU GI[31] is determining the controls of Fe-oxide nanoparticle production, the influence of biological intervention and perspectives for surface modification.

[31] Technical University, Environment and Resources, the Agricultural University, Environmental Chemistry Group, Department of Natural Sciences, NanoGeoScience Group, Geological Institute, University of Copenhagen.

Projects are at the exploratory level; they aim at sophistication of the existing, bulk technology.

b) Nano-materials for Immobilisation and Degradation of Waste
Waste repositories for non-degradable waste, such as heavy metals from fly ash or spent fuel from nuclear power generation, require special containment or treatment systems. Strategies include immobilisation in a stable solid phase or impermeable liners and reactive barriers to slow or prevent transport in groundwater. Natural nano-particles are already playing a role; development will improve their properties.

Swelling clays such as bentonite, have long been used as liners for waste canisters and for landfills where municipal waste and fly ash are dumped. The clay itself is reactive and its ability to incorporate water in the mineral structure makes a tight seal to prevent further water movement. However, landfill liners have been improved by adding reactive components, for example by adding metallic iron, Fe(0). The crude but effective, patented 'Iron Wall Technology' uses ground scrap steel mixed with sand, filled in a trench dug with a bulldozer across the path of a groundwater pollution plume. Dissolved, redox sensitive pollutants are reduced as the iron rusts and the Fe(III)-oxide produces surface area for adsorption of other toxic components. An active component of the Iron Wall is green rust, a mineral of the layered double hydroxide (LDH) mineral family. In cooperation with several industries and research organisations, researchers from KVL IGV, DTU ER and GI KU NanoGeoScience are investigating ways to engineer LDH nanoparticles to improve effectiveness and increase security for immobilising and degrading toxic compounds. Chlorinated hydrocarbons are converted to less harmful and more easily degradable compounds, nitrate is reduced, and carcenogenic dissolved chromium, Cr(VI) is reduced to immobile and non-toxic Cr(III). This research is at the exploratory level (nano-science stage) but will lead to design of nano-materials targeted for specific pollutants, engineered to dramatically improve efficiency over the crude, existing technology.

c) Dosing of Pesticides, Fertilisers, and Eventually Drugs
Layered-double hydroxide (LDH) minerals are sandwich structures consisting of metal hydroxide layers alternating with interlayers. The interlayers are easy to manipulate so one can design them to incorporate specific compounds and to release them under specific conditions. LDH's can be doped with surfactants, peptides or cyclodextrines in the interlayers or one can create them to host medicine, hormones, pesticides, micronutrients, enzymes, etc, for programmed release. Such dosage control protects the incorporated dopant from deactivation, decreases the quantity of bioactive ingredient needed, minimises the risk of leakage to the surroundings, and reduces cost. LDH's with trapped enzymes can be coated on electrodes to produce sensors for which transformations are catalysed by the enzymes. The KVL group is focussing on design of LDH's through knowledge of their nanoscale properties. Some LDH materials are currently on the market but the manipulation of LDH to produce dosing products or censors is at the exploratory stage.

Environmental assessment
a) Optimising natural processes for removal of unwanted substances in drinking water is indeed an environmentally beneficial approach, especially if the natural removal properties can be enlarged without the additional use of

energy or material resources. As with the modified starch polymers, there may be other technologies available against which the environmental impacts should be compared.

b) Problems of pollution of the ground water from deposits of toxic materials and compounds ranks high on the agenda since the possibility of extracting clean water from the ground by many is felt to be an essential right. Thus improvements of the technologies to ensure the supply of clean water are important. It must be considered to what degree the new nano technologies are environmental improvements of existing (or development trends in the existing methodologies), what are the environmental impacts through the life cycle of the technologies, e.g. what are the use of energy and material resources, how are the materials disposed of when used etc.

c) Excess use of chemicals due to overdosing of pesticides, medicine etc. is environmentally important. The developments of technologies such as LDH that may facilitate a more optimal use and less spillage of chemicals will probably be an environmental benefit. As for the other methodologies it should be assessed whether the environmental impacts of using the new methodology during the life cycle balance out the impacts of the problem we are trying to solve.

5.6.1.5 Case: Nanoparticulate starch as a potential heavy metal and hydrophobic absorbent[32]- innovation for novel adsorption technologies

The pollution of water by heavy metals and toxic organic compounds pose a tremendous and growing global environmental problem. Among a multitude of technologies developed for removal of toxic matter in the environment, adsorption technologies based on biomass have considerable potential and have been extensively studied. Examples have included studies on absorption of metals, oil or other pollutants by chemically modified wood fibre, plant fibres or bark. Starch is one of the most significant renewable biopolymer resources on earth, with global annual production of pure starch amounting to some 40 – 50 million tones, and is therefore an outstanding raw material for a number of applications (Ellis et al., 1998 *J.Sci.Food Sci*. 77, 289). Thanks to recent cross-disciplinary developments in biotechnology and polymer science (e.g. Blennow, 2004, In: Starch in food: Structure, function and applications. Eliasson, A.-C. ed., p 97) the nanostructures of starch can now be specifically engineered to possess vastly different chemical and physical properties, many of which are industrially important.

One important challenge for the coming decade will be to explore the potential of starch for bulk applications in demanding and innovative hydrocolloid and solid systems. This will include the development of functionalised renewable biomaterials and more effective environmental adsorbents (e.g., for flocculation of heavy metals, Crini, 2005, Progr. Polym. Sci. 30, 38). Starch deserves particular attention in this respect as it provides interesting and attractive types of physico-chemical characteristics, chemical stability, high reactivity and selectivity towards a variety of compounds, resulting from the presence of chemical reactive and functional groups (hydroxyl, phosphate) and hydrophobic channels in the polymer matrix. Of specific interest is the recent proof of principle for the possibility of generating highly phosphorylated and thermally stabilized starch particles directly in the

[32] Data for this case has been provided by senior professor Andreas Bennow, The Royal Danish Agricultural University, and senior researcher David Plackett, Risoe national Laboratory.

plant based on work carried out at KVL (Blennow et al, 2005 Int. J. Biol. Macromol. accepted) enabling matrix nanostructures (e.g., well defined hydrophobic nano-sized channels) to be functionalized (e.g., with phosphate).

These particles have been engineered to possess increased capacity for interactions with heavy metals and can potentially be improved for better selectivity as well as for selective hydrophobic interactions brought about by engineering the dimensions and the phosphate positioning within the nanochannels.

KVL is currently pursuing research on the mechanisms of adsorption of cupper ions to nano-engineered starch using EPR. At the Danish Polymer Centre (DPC) at Risoe National Laboratory facilities for characterization of the nanostructured starch is fully established enabling disclosure of fundamentally new information concerning its absorption properties and other features using the wide range of state-of-the art techniques available within our two organizations. Specific methods available include SEM, ESEM, TEM, AFM, CLSM (confocal laser scanning microscopy), XPS (X-ray photoelectron spectroscopy), FFF (Field Flow Fractionation), HR-MAS-NMR and ToF-SIMS (time-of-flight mass spectrometry).

From an industrial perspective, Denmark has strong and internationally competitive research activity in this field and Danish industrial groups (e.g., KMC and ISI, Cerestar-AKV) are firmly established with activities to pursue, develop and commercialise functionalized bulk biopolymers which may form the basis for the suggested eco-innovation.

Environmental assessment
The use of filters and adsorbents for removal/concentration of toxic materials in the environment is an important means for reducing potential environmental impacts. Several options have been used through the years e.g. membranes and active carbon and are well-established technologies. The possible environmental benefits of using nanoparticulate starch must be evaluated through an assessment of the environmental impacts during the life cycle of the nanoparticulate starch compared to other filtration/adsorption techniques. The production in-vivo in green plants may be an environmental benefit. It must also be considered what additional benefits could be offered by using the starch based materials compared to active carbon or others, in terms of e.g. a more specific functionalisation of the adsorption.
The assessment must also consider that by using biomass and farming land such a production withdraws materials from the pool of biomass. An important question is: What is the best way of using biomass?

5.6.1.6 Case: Nanoporous materials for hydrogen fuel and diesel cleaning – eco-innovation in mobility[33]

Transport remains one of the major causes of air pollution such as NO_x VOC, CO2 and particles, due to continuing and dramatic increases in the numbers of cars as well as the kilometers driven globally. EU environmental regulation has promoted innovations in environmental catalysts which has decreased these emissions substantially but problems remain particularly with diesel emission, noticeable in the form of particles. New stricter EURO IV emission standards for petrol and now also diesel cars necessitate further innovation in environmental catalysts. But innovation for new fuel systems are also

[33] Data for this case has been provided by professor Claus Hviid Christensen, Center for Sustainable and Green Chemistry, Department of Chemistry, DTU.

undergoing within the automotive sector though many technical problems remain here.

At the Technical University of Denmark (DTU), an interdisciplinary research team from NanoDTU has invented nano materials that improve the safe transport of hydrogen and ammonia. This innovation has implications for the development of fuel cell driven cars as for diesel cleaning. Technically, both of these opportunities rely on the use of self- generating nanoporous materials that allow unprecedented high storage capacities. Scientifically, the progress relies on the research in catalysis and nano materials, where DTU is among the world-leaders.

The technology aims particularly to solve the long-standing problem of reversible, high-density storage of hydrogen in a safe and environmentally acceptable form. This is one of the Grand Challenges in bringing life to a Hydrogen Economy, where hydrogen is used as a clean fuel for stationary and mobile units. The technology makes it possible already now to meet the 2015 targets set by the US Department of Energy in the technology road-map developed for mobile units. With the new technology, it will be possible e.g., to drive efficient fuel cell cars without e.g., any CO2-emissions.
As a spin-off from the main technology, it has also been possible to develop a new system that will allow safe transport of ammonia for use in selective catalytic reduction in diesel or lean-burn vehicles. With this new system, all maintenance and recharging can be performed at the regular service intervals of e.g., 25.000 km. Hereby a breakthrough in diesel cleaning technologies is achieved.

Thus, the two new technologies may contribute in important ways to materialize a Hydrogen Economy and for eliminating the NOx-pollution from mobile and possibly also stationary units, which to day represents a serious environmental problem.

Within the last year, the research breakthrough has resulted in three patent applications and as off April 2005 the commercial potential is being explored in the Danish start-up company AMMINEX A/S, which is a spin-off from DTU that will market and further develop the technologies.

Environmental assessment

Demand for transport is growing rapidly, and this has implications across many areas, including energy consumption, global warming and human health. Fuel cells cars constitute one potential aim for reducing the pollution and energy use. As mentioned one challenge for the potential use of fuel cells is the storage of hydrogen, another is the reduction in efficiency due to the conversion loss from the storage to hydrogen.

For the currently used technologies, catalytic cleaning of engine exhaust constitutes a major leap towards reduction of the pollution with nitrogen oxides and VOC (both contributing to photochemical smog) and for diesel engines additionally reduction of emitted particles constituting a major health hazard. Thus improvements in this area will beneficiate the environmental performance of existing car engines.

As for the case study above it is difficult to draw more specific conclusions concerning the overall environmental benefits of the technology because the environmental assessment must include the total system of producing the engines and the hydrogen, through the use and maintenance to the final disposal. This should be compared to currently used technologies (including their potential developments in energy efficiency, catalytic pollution reduction etc.).

5.7 Conclusion

The Danish nano innovation system is still at a very early and quite fluid stage of formation. We are talking more about path creation in nano science than traceable technological trajectories. But it is also clear that these technological trajectories are in a critical stage of materialising right now and will emerge on a larger scale in the coming 5-15 years. The current phase of path creation seems therefore crucial for the direction nanotechnology is going to take. Even though it can be contested to which degree nanotechnology is a new technology (or just a hype redefining existing practices) there are clear signs of novelty in the organisation of knowledge production and in the modes of learning in the Danish nano community. There are new patterns of problem solving activities related to the rise of the nano domain.

Eco-innovations are, however, to quite a large degree excluded from the attention rules and they are weak in the search rules with some exceptions though. Despite frequent references to considerable eco-opportunities of nanotechnology in the general nano debate internationally as well as in Denmark, environmental issues are only moderately part of the normal problem solving activity of the Danish nano technological community.
A very wide range of nano related eco-potentials have been identified none the least, possible making up the most detailed mapping of nano eco-potentials made so far. This is due to the fact that there are some intrinsic features of nanotechnologies that may facilitate eco-innovation, by making more tailored, efficient, selective and intelligent materials and products. Quite many nanotechnologies thus possess eco-potentials, even though they are not being developed with environmental benefits in mind.

In all 39 suggested research areas/technologies are identified which offer eco-potentials within eleven different main nano research/technology areas.
These may say to contribute with environmental opportunities by aiming at:
Smart tailored products – for i.e. greater resource efficiency.
New materials - for less resource use and new properties.
Energy production – developing efficient or alternative energy systems to fossil fuels.
Environmental remediation - for more targeted handling of pollutants.
The 39 suggested research areas/technologies cover a very broad range of research and technology themes at very different development stages.
Diversified assessments of opportunities and risks are therefore necessary.
It is generally too early to pick the environmental winners given the very early stage of development and the immature materialization of nanomanufacturing and the many new research questions and technologies under way. Many (most) of the identified nano eco-potentials are at an experimental stage of development. Others are in early production, e.g. some functional surfaces techniques, and a few, mainly catalysis and some sensors, are fully commercialized.

What we can say is that there are many very interesting eco-potentials related to different nanotechnologies, and that there are grounds to pursue and investigate the Danish eco-potentials of nanotechnologies further.

The interesting thing about the identified eco-potentials is that they in some cases may offer novel solutions to environmental problems. This may especially be expected from the mentioned groups of fundamental nano research areas into new materials and functional surfaces (from group 1 and 2 from above) which could lead to more radical and possibly widespread systemic eco-innovations. I.e. creating materials and products which have integrated "eco-properties" (such as being anti-bacterial, self/easy-cleaning, insulating, strong and light, self-monitoring and -diagnozing) for greater resource-efficiency, selectivity and durability. This could allow for more ongoing and decentralized smart eco-solutions and thereby a more preventive and integrated approach than practiced today. But this is also where the environmental orientation amongst the Danish researchers is most limited and where it is least likely that the eco-potential will be exploited.

Also group 4, environmental remediation, may offer new approaches to environmental remediation by using nanoparticles to make more targeted action towards specific pollutants and by exploiting the cleaning capacity of natural systems better. The strong catalysis area is well-established and does not currently give expectations of major novel solutions in the coming years, though there are exciting developments within diesel cleaning. However, the novel environmental benefits may lie in the contributions this research makes to obtaining breakthroughs within hydrogen based fuel systems. The mapping shows that nanotechnologies in important ways may contribute also to other new renewable and/or more efficient energy systems (group 3) and thereby to the central climate problems. Here we find some of the more commercially promising, but still emerging, nanotechnologies where Denmark holds quite a strong position too and which may have an impact in the coming years.

We cannot conclude that nano technologies are green as such; it is, as yet, a much too diverse technological field for such a general statement. But the identified eco-opportunities could overall make important contributions to a more resource efficient economy if materialized, though depending very much on how they are used and how they feed into other technologies.

The very strong Danish competencies within catalysis should provide a good basis for building a strong position within "green nanotechnology" here. But much indicates that this will not take place on its own. The emerging technological paths are only moderately green and many of the identified eco-opportunities are being neglected. Even though environmental targets are not purposefully pursued in the nanoresearch environmental advances may still be achieved through the general nanotechnology developments. In fact that is nowadays the case with many eco-innovations (since eco-innovation has shifted somewhat from add-on to less well-defined integrated technologies). But the environmental advantages are likely to be harvested later and to lesser extent and some will not be pursued/selected at all.

Naturally, it makes a difference if the research and development is aimed at e.g. the substitution of scarce or toxic materials, to improve the degradability and recycling abilities of materials and products, achieve dematerialisation etc., particularly if the goal is to find solutions to specific environmental problems or to achieve major systemic change.

The unexploited eco-potential is noteworthy considering the generally strong Danish competencies and policies on environmental issues. Most surpricingly perhaps in the water area where Danish industry holds strong competencies within water cleaning and supply, but where there is limited nano research and no linkages to the water industry.[34] This illustrates the possible gaps between the high expectations and visions of nanotechnology and the actual processes taking place.

The suspicion of health and environmental risks from nanoparticles and so far lacking measures how to handle these in risk and safety procedures as discussed in section 5.3, seriously questions the environmental benefits of the nanotechnologies based on these particles and at least calls for a precautionary approach until more is known. Also, there are knowledge gaps about the wider environmental impacts of the other nanomaterials and varies nanotechnologies.

It is therefore important to investigate further into the eco-potentials and impacts of the different listed nanotechnologies and research areas and clarify the possibility to set up measures how to handle the new risk challenges nanotechnology poses. We need in other words both to know more about the opportunities and about the possible detrimental environmental impacts. The very early stage and therefore high uncertainty of some nanotechnologies means that it makes little sense to make environmental assessments of these. Rather in these cases there is a need for more research and development into these areas which includes their possible eco-potentials and -risks.

The many identified eco-potentials overall illustrate the very early and fluid stage of nanotechnology development globally and in Denmark, showing much creativity as streams of new research questions are raised. There are multiple future possible nano technological paths. Which ones are going to materialize themselves and the position they may come to play on the market is currently highly uncertain – and depends also on policies. The high uncertainty means that we need to acknowledge that there are limitations as to how much we can know now on both environmental opportunities and risks.

5.7.1 Problems to address by policy

On the basis of the analysis made as well as input from the innovation workshops and policy workshop held during the foresight project the following key problems are identified which policy should seek to address. A fundamental problem is the long "distance" in the innovation food chain from fundamental nano research to application areas and societal and environmental effects. An overall dilemma is when and how to carry out dialogues and policy measures towards a technological field such as nanotechnology whose technological materialisation in the near to medium future is highly uncertain and very diverse. The early fluid stage of development means that there are good opportunities for influencing the direction of nanotechnology development, i.e. making it greener; at later stages the lock-in into competencies and investments will be greater and transition costs therefore higher.

Eco-innovation in these basic sciences and enabling technologies are likely to have widespread effects into practically all kinds of technologies. It would be a new strategy for environmental policy to focus on these early stages of the innovation food chain, but it may be an efficient way to achieve systemic eco-innovations in the long run. The more specific problems are divided into respectively a risk and an opportunity section.

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[34] Interview with Kasper Paasch, Danfoss Analytical, 7.9.2004.

Barriers in the innovation system to handle nano risks are:
- Weak attention to and means of handling environmental risks/detrimental effects related to nanotechnology
- Uncertainty – we have limited knowledge of the environmental effects related to nanotechnology, none the least because of the very early stage of developments. We are lacking data and knowledge of how to get these. There is rising focus on toxicity but there is also need to focus on "clean nanotechnologies", looking into the different nanotechnologies. Hitherto lacking systematic incorporation of environmental assessments in research proposals (but suggested in EU as well as Danish nano action plan). Existing risk/environmental assessment procedures are not adequate for measuring and handling materials at the nano scale. There are specific problems to address.
- Lacking nano competencies among risk/environmental assessments institutes and experts.
- Nanotechnology mediation is difficult due to complexity, hype and uncertainty - there is a need of dialogues and serious scrutiny.

Barriers in the innovation system for supporting nano eco-innovation are:
- Nano policies, e.g. EU's nano strategy, the Danish nano action plan, only focus on risks and overlook barriers to eco-innovation.
- Weak attention to and belief in nano-eco innovation business opportunities except for the catalysis and energy area (need of regulation to create new markets, need of demonstrations…)
- Difficulty in getting environmental funding for fundamental nano research.
- Lacking environmental competencies in the Danish nano community and lacking nano competencies among environmental experts and policy makers.
- Weak linkages between the nano community (e.g. the new nanocentres) and the environmental researchers/experts and the environmental industry.

6 Policy recommendations: enhancing the focus on environmental and innovative aspects of ICT-, bio- and nanotechnology

6.1 Introduction

This chapter summarises the conclusions from the analyses of ICT-, bio- and nanotechnology in the previous chapters. Following this, policy recommendations are developed aiming at enhancing the focus on environmental aspects and innovative perspectives in future research, innovation and applications related to the three technology areas. The recommendations suggest an integration of policies that often are applied separately and have either environmental problems or innovation support as their main focus.

Section 6.2 presents a framework for the policy recommendations. Section 6.3 summarises the findings from the analyses of the three technology areas and characterises the environmental potentials and risks. Section 6.4 discusses the recommendations for related Danish and EU policy initiatives. Section 6.5 – 6.8 discuss the findings from the analyses in relation to important discourses around environment and innovation and discuss recommendations for research, innovation, application areas and environmental governance.

Section 6.9 presents the policy recommendations.
Environmental policy usually addresses mature technologies looking for substitution possibilities and new applications that may remedy urgent environmental problems. It is quite another issue to address generic and immature technologies, or even, as in the case of nanotechnology, a technology that hardly has materialized yet. This raises new questions on policy instruments which crosses traditional policy domains. The use of the relevant measures in the different stages of research, innovation and implementation and use is here the core issue. When and how shall and will policies seek to influence the (green) direction of technological change? Obviously the relevant interventions and questions raised are different in the idea generation phase compared to the later experimental, early production or full commercial phases of the innovation process.

The technologies addressed in this study are general purpose technologies that may have profound effects on society. In the case of ICT that has already proven to be the case. Biotechnology is having a rising impact on the economy whereas nanotechnology is still in its infancy but with expectations that it may form the platform for a future industrial revolution. We are dealing with technologies that have some similarities in being generic and enabling rather than just being distinct technologies on their own. But they are also

technologies which differ very much in their maturity, technical properties and uncertainties involved. In many applications the three generic technologies will not be standing alone but be parts of more complex products and systems where the combination with other technologies are important for their function and environmental impact. Their impact is not just a determined consequence of their basic features but also dependent on how they are used and which products and systems they are integrated into.
In the following policy recommendations will be developed springing from the analysis undertaken on technology development internationally and nationally within these three technology areas and from the discussions at the project workshops and the final conference January – April 2005. The recommended policy measures will enhance the capability of the Danish national innovation systems and the Danish environmental regulation to cope with the special features and potentials of these generic technologies.

6.2 A framework for policy recommendations

The recommendations in the following paragraphs are based on the identified innovative and environmental potentials from the three studied generic technologies including also the need for framing the environmental priorities in a broader public consensus and handling the environmental potentials and risks arising from the implementation and use of applications. But also the conditions for policy in the areas of research, innovation and environmental regulation and governance have to be taken into account.

Danish competencies within the identified areas of research, development and potential applications have also been included in considering the specific recommendations. If Danish R&D institutions or companies have competencies within some of the analysed fields a focus on this area could create a combined focus on environment, economy and employment. Fields, where Danish R&D institutions and companies may not have strong competencies today, could also become important if technologies within these fields could prevent or reduce environmental problems and resource consumption in Denmark in the future.

The project has taken as its outset that technological change and environmental impacts only in a few special cases will be directly linked the development of generic technologies and the materials or processes following these developments. The major applications and impacts are shaped as results of the activities of research, development and use in a series of major and minor complementary innovations influenced by a number of involved actors and their priorities along the lines of application. Our studies of the technologies and their applications have confirmed this conceptual foundation in relation to all three generic technologies: ICT, biotech and nano, despite their differences both in areas and degrees of application.
This leads us – in accordance also with the framework and methodologies developed in chapter 2 – to differentiate between policies which primary objective is to prioritise, support and

- *guide research* activities and
- *strategic innovation policies*

aiming at transforming new entrepreneurial ideas and results from research into innovations that can be tested in real life situations and enter competitive markets. As a third policy perspective we include a special focus on those mature and market introduced technology applications in products and systems having ‘green’ potentials that are not realised under the present market, production and user regime, but where more stringent

- *regulatory policies or standards*

could provide the difference. In the cases of strategic support for innovation and the regulation of applications a sector or even product domain approach may be needed to reach the intended, anticipated environmental results concerning reduced loads and improved performance.

In addition to the three areas of policy improvements outlined, a fourth and cross cutting area

- *societal environmental governance*

follows from the results of this study. Governance focuses on the need for a broader stakeholder dialogue to handle the legitimacy of the environmental priorities and consider relevant measures to establish consensus - for example about the level of uncertainty concerning the environmental potentials and risks that can be accepted for certain technology applications.

The four policy perspectives are shortly presented in the following. Later in the chapter each of the perspectives are applied in relation to the technology areas.

Ad 1. *Guiding research* to include environmental perspectives, including policy options for assessing research strategies and potential outcomes, creating visions and objectives for areas of research, and setting the stage for prioritising the research to be supported by government and private funds.

Ad 2. Focusing *innovative activities* on the combination of technologies within specific fields of application creates the core elements of strategic innovation policies. The results of such policies should be the creation of new paths for technological development by supporting the critical and highly uncertain first steps of bringing good ideas with potential environmental benefits from the laboratory and sketch board to real prototypes and scale tests. This kind of strategic innovation policy may also include a market support structure based on an open and competitive definition of the technologies and application to be supported. This will sustain the learning modes, visions and strategy building within research and industry in the first infant steps of creating new areas of application without falling in the traps of ‘picking winners’ either by technology or institutions.

Ad 3. *Regulating technology* applications through the regulation of driving forces and institutional frames determining the use of products, the development of consumption areas etc. form the third policy area where a number of different policy instruments will become relevant and the coordination of policies between different policy domains and ministries are in focus.

Ad 4. The legitimacy of the *environmental aspects* and of the problems and solutions addressed within the three technology areas can not easily be developed and managed. The environmental potentials and risks cannot be defined or prescribed only through scientific investigations and consideration, because the uncertainties as well as the stakes are high. The assessment of environmental potentials and risks is highly dependent on the consensus or positions established among the different stakeholders in society and the policies and interventions resulting from this process. A deliberate focus on environmental aspects in research and innovation policies therefore also need to establish a framework of social interactions and policy dialogues focussing on the environmental concerns of different stakeholders and addressing the uncertainties in relation to both potentials and risks involved with new technologies. Environmental governance should therefore be seen as a cross-cutting policy measure in the guidance of research, innovation and applications.

6.3 Overview of the findings from the three technology areas

The studies reported in chapter 3, 4 and 5 of possible future innovations and use patterns involving ICT- bio- and nanotechnology have identified a number of environmental potentials and risks. These findings are briefly summarised in the following paragraphs.

6.3.1 Summary of findings related to ICT

Environmental potentials and risks have been analysed within five ICT-technology application fields: a) development of the environmental knowledge base, b) improved product and process design, c) improved process regulation and control, d) intelligent products and applications and e) reduction of transportation through changes in logistics and mobility needs. The ICT sector in Denmark has a strong position in communications technology and pervasive computing and is one of the leading countries regarding public and private use of ICT.

The analyses show potentials for environmental improvements from the use of ICT-based tools and devices for data collection and processing of more data in more complex calculations. Some tools enable more overall resource efficiency in e.g. industry so that it is the specific aim of the application by the single organisation that determines whether and how environmental achievements are in focus.

The integration of electronic components into products, so-called intelligent products or pervasive computing and intelligent applications, could imply environmental potentials related to automatic optimisation of the function of products, operational feedback to the user, digital product information about maintenance, reuse etc., integration of products into digital networks whereby use might take place during low load cycles of the electricity supply, and digital upgradeable products.

Telework, e-business and logistics are those ICT applications with the most implications for transport behaviour in the future. Telework might imply that regular transport related to commuting and shopping in certain hours is replaced by more differentiated transport needs. Although only a limited amount of employees will be able to telework, this could challenge the existing infrastructure of public transport and strengthen individual transport solutions. Mobile telework will be more widespread as mobile communication solutions will offer the same facilities at comparable costs as those offered from the office. This may enable an increase in business travel transport in interaction with the ongoing globalisation of manufacturing and trade. Within freight transport e-business could lead to more transport of small batches with high urgency to professional and private customers. The concept of just-in-time production in industry could also imply more transport due to the request for more frequent supply of small batches of materials and products. Logistic tools might optimise the amount of transportation within these organisational and economic conditions.

The identified environmental potentials within the five application fields play today no significant role in the development and use of software and ICT-equipment. Achievements within these fields demand environmental regulation of the respective application areas influencing the priorities made by the users and the dominant driving forces for innovation and implementation.

An increased amount of electronic products, miniaturisation of products, pervasive computing and a more dispersed use of sensors and other devices could imply increasing problems in the future with electronic waste. Increased use of pervasive computing and increased wireless communication might cause health problems due to increased electro-smog and safety problems due to interference between different devices operating in wireless networks. Efficient implementation of the EU directive about hazardous substances in relation to electronic products (RoHS) is necessary in order to achieve the planned substitution of some toxic materials are substituted in the future. Furthermore, efficient implementation of the directive concerning electronic and electrical waste (WEEE) is necessary in order to obtain increased recycling of materials etc. from the products.

6.3.2 Summary of findings related to biotechnology

Positive visions of the environmental contributions of biotechnology developments have been prevalent for 25-30 years but, as the foresight on biotechnology has revealed, the environmental visions have historically not been the drivers of innovation. There were strong efficiency drivers, however, especially for pharmaceutical and agricultural applications of new biotechnology, and they came to dominate the development. The environmental agenda only recently has come more to the fore, amongst other with a number of reports, policy documents and discussions papers. These reports and policy documents refer to a number of more specific biotechnology developments with environmental perspectives. The motivations for these developments are referred to as an increasing emphasis on problems in the chemical using industries, on resource scarcities and on the need to 'clean up'. Together with environmental regulation, government priority setting and biotechnology regulation, these have been drivers of an increasing, but still small part of biotechnology, with potentials to address environmental issues.

In Denmark, enzyme technology comes out as a key technology for realisation of environmental benefits of biotechnology. It is demonstrated in the environmental assessments that enzymes in the referred cases address and reduce toxic agents, energy consumption and resource use, and references are made to representatives in the industry as well as researchers, who expect that enzymes will contribute even further by increasing efficiency in production and use, by being applied within more industries and by being further used in industries already using enzymes. Increasing focuson sustainability is referred to as potentially contributing the application of enzymes.

With regard to developments within bio-ethanol and bio-polymers, environmental concerns have been key motivators for innovation, as well as concerns for fossil fuel scarcity. The environmental assessments of these areas of biotechnology, however, demonstrate a need for further evaluation and debate of their perceived environmental advantages. Any use of biological resources may in the future have to address the fact that biological resources

are of limited availability, and any environmental claim will, therefore, have to compete with alternative uses of such resources. Using arable land and agricultural crops for bio-ethanol and bio-polymers with the purpose of substituting fossil fuels, therefore, probably has to compete with the use of the same land and crops for substituting fossil fuels in the energy sector.
With regard to the application of new biotechnology for monitoring and remediation, it has been foreseen to contribute to cleaning of a number of pollutants. An important barrier for further research as well as development has been referred to as uncertainties regarding also the negative consequences. Private research and development primarily takes place in the US; however, further research into the potential positive and negative consequences still seems a prerequisite for a debate on the acceptability and extent of application.

6.3.3 Summary of findings related to nanotechnology

The Danish nano innovation system is still at a very early and fluid stage of formation. The current phase of path creation seems therefore crucial for the direction nanotechnology is going to take. Despite frequent references to eco-opportunities in the general debate on nanotechnologies the problem solving activities and the emerging technological paths in the Danish nanotechnology community are only moderately green. Consequently many eco-opportunities might be neglected. Environmental risks are also overlooked although there is a rising, but new concern about these within the Danish nano community.
The environmental aspects related to nanotechnologies are as yet very uncertain. There are knowledge gaps both about the environmental risks and the eco-opportunities, because of the very early stage of development. There is rising international concern on environmental and health risks related to nanoparticles which questions the overall environmental impact of nanotechnology and which is in need of urgent further inquiry.

Quite a wide range of nano related *potential* eco-innovations have been identified, in all 39 within eleven different nanoresearch- and technology areas, showing the very generic applicability of nanotechnology. These may contribute to remedy the environmental problems in four ways: 1) ‘Smart tailored’ eco-efficient product. 2) New materials with new properties, which both could enable less use of energy and other resources in the manufacturing or the use of these products and materials, 3) Technology for renewable (fuel cells, solar cells, windmills) or more efficient energy systems and 4) Environmental remediation with more targeted dosing of e.g. hazardous chemicals and more targeted treatment of pollutants and efficient catalytic cleaning. Many of these are in a very early stage of development, hardly technologies yet, but in the medium to longer term (10-20 years) they may offer novel, often radical, solutions to many environmental problems if the technological obstacles are overcome. Environmental problems related to for example energy supply and transport (climate change), resource and energy use, use of chemicals, and treatment of waste and wastewater. Within catalysis and energy (fuel cells) Denmark already has quite strong competencies and market positions which could form the basis for building a strength hold in “clean nanotechnology”.

Most of the identified nano eco-potentials are, however, not likely to be pursued in the current research and development trajectories in Denmark and are in need of policy action to be realized.

The main barriers for achieving eco-innovation and sound risk management, related to nanotechnology, are:

- Lacking environmental competencies in the Danish nano community and lacking nano competencies among environmental experts and policy makers.
- Lacking awareness of and belief in nano related eco-business opportunities (need of demonstrations, need of regulation to create new markets)
- Difficulty in getting environmental funding for fundamental nano research.
- Weak linkages between the nano community and the environmental researchers/experts and also the environmental industry.

Hitherto lacking systematic incorporation of environmental assessments in research proposals (but suggested in EU as well as Danish nano action plan). There is rising focus on toxicity but there is also need of focus on 'clean nanotechnology'.

Existing risk/environmental assessment procedures are not adequate for measuring and handling materials at the nano scale.

6.3.4 The character of the identified environmental potentials and risks

The identified environmental potentials within the three technology areas are of very different character with respect to the type of environmental strategy they represent: enhanced environmental knowledge, cleaner technology with focus on prevention or reduction of environmental impact at the source from products, materials and processes, and improved treatment of pollutants either by environmental technology like catalysts or in nature. Some examples are:

- Enhanced data collection and knowledge exchange about the environment through the use of sensors, ICT-based models, ICT-based knowledge networks etc.
- Improvement of energy technologies like solar cells and fuel cells based on nanotechnology and nanoscience.
- Improvement of resource efficiency through ICT-based process design and control of processes and products, use of enzymes as auxiliary chemicals in products and processes etc.
- Design of materials enabling reduced environmental impact, like biomass based plastic with fewer additives and materials based on nanoscience with surface properties that requires less cleaning.
- Improvement of cleaning process efficiency like more efficient design of catalysts based on nanoscience or remediation of pollutants in nature using nanotechnology.

In most cases *the environmental potentials* cannot be realised through the application of a single technology, but are requiring a combination with supporting technologies, like the need for fuel supply for fuel cells, handling of waste and in some cases also certain innovation and application patterns. ICT-programmes for logistic planning, for example, can be used for a reduction of the amount of transport and thereby the amount of emissions from transport, but such programmes can also optimise the logistics according to other economic and performance parameters. Today there is only limited focus on the potentials of reduced amounts of transport through improved ICT based logistic systems and the achievements so far have been offset by the increase in transportation due to the trends towards a globalisation of industry and trade. The same is the case for the application of fuel cells, which will be dependent of the combination with other technologies for producing and storing energy and for new ways of constructing products using the fuel cells - all of which will contribute to the overall performance and impacts of the application of the nanotechnology.

Potential risks have also been identified within all the three technology areas. Some of these risks are closely linked to a technology like the possible environmental and health impact of different types of nanoparticles, while others are depending on the patterns of application and use. The environmental impact from e.g. sensors distributed in big numbers in the environment could become an environmental problem, but today the prices are so relatively high that sensors are not disposable and are not be left in the environment. Some possible risks related to the three technology areas that need to be included in the future assessment of risks to environment and health, are:

- ICT: radiation from wireless communication; the use of hazardous chemicals and materials in ICT-equipment
- Biotechnology: allergy related to increased use of enzymes; release of genetic modified microorganisms from industry and bio-remediation and interference with existing sustainable usage of biomass
- Nanotechnology: emissions of and exposure to nanoparticles in manufacturing, use and disposal of nanoparticles, and in materials and products based on use of nanoparticles.

The discussion of risks related to radiation from wireless communication are known from the discussion about mobile phones and other similar types of equipment and shows how different the results produced in the assessments are interpreted and valued among different stakeholders. If pervasive computing is expanding as foreseen by proponents within this field these types of problems might grow in the future and the electro-smog problem become a new field of pollution.

Also the risks related to allergy produced by enzymes and genetic modified micro-organisms are known and are also showing rather different results in the assessments of their documented and potential risks. The controversies were demonstrated clearly at the policy workshop organised by the project in February 2005.

The example of nanoparticles shows how those properties, which are seen as excellent and the core functional contribution from the nanotechnology by the researchers and industry, also can be those that imply risks to environment and health, like the relative large surface area, the improved and high reactivity, the limited physical dimensions which enable penetration etc. (Norges forskningsråd 2005, p.25).

6.4 Environmental governance as cross cutting policy measure

Environmental governance, defined as policies creating platforms and methods for different actor groups to be given voice and developing frameworks for how decisions are made on issues of public concern, should be an integrated and important element of policies guiding and supporting research and strategic innovation and regulating the application of technologies within the three areas. An important aspect of governance concerns how issues and actors are being defined as inside or outside (the responsibilities of) a specific area of development and thereby what is legitimate to discuss as environmental (and other societal) potentials and risks. This includes on whose premises these boundaries are drawn. An important aspect of this is the inclusion and exclusion of actors in the processes of planning and managing public and private research and innovation. The reputation of biotechnology and nanotechnology might be more fragile than that of ICT, but for all three areas there is a need for focus on the legitimacy of the environmental potentials and risks.

Some general governance aspects of the three technology areas include:

- Due to the very capital-intensive character of the three technology areas research organisations and companies engage in highlighting expectations and potentials very early to influence other stakeholders. This makes sound and critical assessments of the environmental aspects important, but also difficult. Promises should be challenged with respect to the necessary breakthroughs in research and innovation and the need for building infrastructures and complementary support technologies.
- The assessment of the environmental aspects depends on the frames and values of the actors assessing the impact. The tacit visions and fears of researchers, consumers, citizens, industry etc. should be made visible and made subject to social deliberation, review and negotiation.
- In the future the use of patents for protection of intellectual property may further limit public and governmental insight and scrutiny in relation to the potentials and risks of new technologies. This tendency might be enforced by the increased focus of universities on co-operation with commercial partners, setting up start-up companies, patenting and the need for attracting external funding for research.

An important part of governance relates to the legitimacy of the problems and the solutions, which are addressed in research, development and application. The experience from genetic modified food shows that the discussions cannot be limited to expert assessment of quantifiable risk aspects, but need to include all stakeholders, which feel affected, in assessments of:

- the relevance of the problems addressed by the technology, and
- the solutions ‘offered’ by the technology, including whether there are other solution strategies, which might solve the problems in a way which implies less uncertainty in relation to environmental potentials and risks.

6.5 Recommendations for related Danish and EU policy initiatives

The linking of environmental issues with innovation policies is on the agenda of both Denmark and the European Commission expressed through strategic initiatives and programmes. These programmes create an opportunity to implement the recommendations from this project in already established strong policy frameworks that still are open for improvements and specifications concerning the detailed measures and priorities. Three of the most relevant policy programmes and initiatives and recommendations for the support of eco-innovation are discussed in this paragraph.

6.5.1 The Danish government's plan for a strengthening of 'green technology'

The Danish government has in its recent governmental framework said that the development within 'green technology' will be strengthened, with energy and fuel as two possible areas. We propose such an initiative should include elements from all the four types of policy perspectives that we are proposing: guiding research, supporting strategic innovation, regulating application areas, and governing the framing and management of environmental potentials and risks. There are ways to shape a 'green technology' initiative that can accommodate the findings and recommendations from this project. The initiative could be a relevant place to cater for the specific problems relating to certain areas of application of technologies in products and systems and to regulate their use within areas of production, trade and consumption, which are environmentally important in terms of their consumption of material and energy and their environmental impacts.

In contrast to the above outlined perspective, an initiative could end up focussing only on the development and promotion of the generic technologies as such and lack the emphasis on their applications and impacts. The risk is that the fairly general and international support for generic technologies as the most important area for government support policies results in action plans picking and promoting potential 'winners' by projecting their innovative and environmental performance. Instead the areas of support should respect the rather high uncertainty concerning the performance and impacts and focus on creating variety and supporting creativity in identifying different solutions and applications by involving stakeholders from research and from areas of application in industry and society. A Green Technology programme would need to have support not only in the Ministry of Environment, but also in Ministry of Science, Technology and Innovation and in the sector specific ministries in order to secure the necessary funding and support in related sector policies.

6.5.2 The Danish High Technology Foundation

Another important strategic programme is the Danish government's creation of the High Technology Foundation. This has already from the outset defined ICT, biotech and nanotech as its primary focus areas concerning the technological base for future strategic innovation, which also is signalled in the name of the funding body. The application areas that the High Technology Foundation are expected to focus upon are not defined by means of the technology base but in relation to rather broad and for the society important problems to be handled (Ministeriet for Videnskab, Teknologi og Udvikling 2004):

- Better food and medicine for a long and good life
- Knowledge at the right time and place
- Energy for the future at the right price
- New materials with unlimited possibilities

The limitation, though, might eventually be that the visions for all four application areas are mainly described through the use of ICT-, bio- and nanotechnology, which indicates that the foundation maybe mostly is focusing on technology-based strategies. This is also the case for the studies of this project, so the important question is whether the technology base defined for the High Technology Foundation also will be limiting the outreach and perspectives of the supported research that the foundation will support, or if the obvious importance of integrating the generic technologies in more complex and integrated technologies in relation to the specific applications will open for studies also of these applications and the benefits and impacts that may follow them.

The vision ‘Better food and medicine for a long and good life’ is for example mainly seen as a biotechnology based vision and not as an area relating the research to the social conditions created in modern every day life and work, which may limit the research to the production and product component perspective not including the fields of applications and impacts. Environmental aspects of ‘white’ biotechnology are not mentioned as a priority area.

The vision ‘Energy for the future at the right price’ in contrast includes environmental aspects as a main objective. It focuses on the substitution of fossil fuel by a combination of renewable energy and increased energy efficiency. The strategy for the realisation of this vision builds upon more intelligent energy supply and energy consumption where the supplying units and the consuming units are linked through pervasive computing so that energy consumption takes place when there is a surplus of energy supply. Also nanotechnology is mentioned to have potentials for the future development of wind turbines and fuel cells.

The vision ‘New materials with unlimited possibilities’ includes some environmental aspects of nanotechnology: the possibility to produce concrete with less consumption of energy and materials and the possibility of nanostructured functional surfaces to become for example self-cleaning.

We have not in this foresight identified energy savings or networking of intelligent products with energy supplying units as visions in the development within intelligent products and pervasive computing. This might indicate a need for dialogue with the actors within intelligent products and pervasive computing about the possibilities for energy savings and networking of intelligent products with energy supplying units. The environmental potentials related to nanotechnology are among those potentials our analysis has identified within the nano community. We propose that the environmental aspects of all three technology areas - ICT, nanotechnology, and also biotechnology - get a high priority in the future activities of the High Technology Foundation. This could include formal participation of environmental authorities, environmental NGO’s and eco-innovation researchers in the further shaping and management of the Foundation’s activities.

6.5.3 EU’s Environmental Technologies Action Plan (ETAP)

The European Union’s Environmental Technologies Action Plan (ETAP) is often highlighted as one of the policy tools that can become a major support for the development of ‘green technology’. The Plan contains eleven priority actions for the Commission, national and regional governments, industry and other stakeholders to improve the development and uptake of environmental technologies. These include:

- Setting up technology platforms bringing together researchers, industry, financial institutions, decision-makers and other relevant stakeholders within different technology areas in order to build a long-term vision on the research needs and future market developments.

- Developing and agreeing on ambitious environmental performance targets for key products, processes and services.
- Mobilising financial instruments, both within and outside the EU, to share the risks of investing in environmental technologies, with a focus on climate change, energy and small and medium-size enterprises (SMEs).

The establishment of technology platforms is closely related to the subject of this report. One of the technology platforms, which have been established within ETAP, is the platform for Sustainable Chemistry, which aims at supporting the long-term success of the European chemical supply chain (European Technology Platform for Sustainable Chemistry).

Since this foresight project has a focus on reduction of chemical impact on environment and health it is relevant to take a closer look at this platform as part of the development of policy recommendations and their implementation. The platform intends to deliver a long term vision for sustainable chemical technologies in Europe and a vision for a competitive and sustainable chemical industry. The focus of the platform is industrial biotechnology, materials technology, and reaction and process design. Included in the aims of the platform are horizontal issues like regulatory safety assessment, which are argued to constitute barriers to the adoption of new chemical technologies and the continued use of existing technologies.

The platform draft also includes the perspective of public acceptance of chemical technologies, but takes as the outset that there is a deficit in the public understanding and expresses a need for societal acceptance of chemicals and the communication of actual risks (as opposed to what the description of the platform call ‘perceived risks’) of the chemicals to the broader society. The draft mentions ‘consensus among stakeholders on methods for and interpretation of chemical risk assessments’ as an objective although no specific stakeholders are mentioned and the understanding of environmental governance, as described above, has its primary emphasis on risk *communication* from experts to the broader public and not on *dialogue* between industry, researchers, government and NGOs.

Even though this specific technology platform is not taking the broader perspectives argued for in this study into account in a very deliberate and explicit way, there could be important contributions to gain from ETAP if governments and innovation bodies, industry and NGOs engage in defining strategic relevant technology platforms with objectives supporting environmentally sound technology developments in different areas of application with high degree of legitimacy. Also Danish government and the agencies involved in implementing the Danish ‘green technology’ strategy should assess the potentials of engaging in the construction of such platforms under the ETAP umbrella.

6.6 Guiding research and research policy to include environmental aspects

An important question to address in future research policy is when and how to carry out dialogues and other policy measures in relation to research within the three technology areas in order to obtain an enhanced focus on environmental potentials and risks.

Research is not just one type of activity. An enhanced focus on environmental potentials and risks related to the three technology areas calls upon at least the following three types of research:

1. Policy research which itself can guide research policy and research planning
2. Technology research developing processes, materials etc. with environmental potentials
3. Environmental research assessing environmental potentials and risks, either pro-active research related to ongoing technology research or research related to real-life application of technologies and products

When it comes to *measures* for integration of environmental aspects and concerns into research and research policies the following types of guidance seem to be the relevant ones:

- Visions for the anticipated use and outcomes as a means of shaping the research policies and also the rules of attention and micro priorities in the research community, maybe developed through policy research like Constructive Technology Assessment and Green Technology Foresight
- Environmental screening of research proposals as a way of qualifying the decisions and priorities made in research funding
- Guidelines for environmental assessment of technology research, where some important questions concern how such assessments are carried out in a preventive and holistic way and how the assessments obtain legitimacy

6.6.1 Visions as guidance of research policy and research

Research policy raises the question, when it is possible to say something about the environmental potentials and risks related to some technology research. Could too early regulation limit a creative process? Could too late regulation imply that the vested interests in terms of equipment, external expectations etc. are too high and the direction of the research difficult to change? If technology research was an open process rather weak and guidance oriented measures could be adequate means of influencing the visions and priorities of the research policies and the research process. However, priorities concerning fields of technology research often focus on rather general assumptions of the importance of technologies and the possible results coming from economic investments in these areas of research. Even though there, as earlier discussed, might not be a direct link between research, innovation and application, researchers and policy makers often produce quite far reaching and presumptuous promises for the societal and sometimes also environmental benefits to be expected from new research areas. Since researchers often are using public communication in presenting their visions and promises to government, ministries, NGO's etc. part of the research policy process should challenge these promises in order to create a better knowledge about the social and technical prerequisites and assumptions the promises are based on.

The dialogue around expectations and promises may seem quite difficult in relation to nanotechnology and nanoscience, where there is rather little experience with the technologies and their application. The materialisation of the applied technologies will only take place in the near to medium future and is highly uncertain and very diverse. There is also limited knowledge about the environmental effects related to nanotechnology. However, also in relation to ICT and biotechnology there is a need for more dedicated focus on the environmental potentials and risks in the research strategies and the research itself than has been the case up till now. Therefore the same strategies and tools for research guidance can be applied in relation to all three technology areas.

Dialogue processes with broad participation of interested stakeholders, including organisations that seldom are invited into planning and management of research (e.g. consumer organisations, environmental organisations and trade unions) might be a way of enabling assessments of the social and technical prerequisites of technology breakthroughs and of the environmental (and other societal) aspects of research. By being based on different types of knowledge and experience and by having broad stakeholder participation the results may achieve broad societal legitimacy.

6.6.2 Applying methods from technology foresight

The tools applied in this foresight project are relevant in all three types of research (policy research, technology research, environmental research):

- Analyses of emerging applications
- Analyses of attention and search rules in research and innovation
- Dialogue workshops among involved and concerned stakeholders
- System- and lifecycle-based environmental assessments

Among the tools and strategies applied in similar activities in other European countries are

- Guiding principles for research
- Dialogue among stakeholders about near-future applications
- Upstream public involvement in research
- Constructive technology assessment as an integrated, but independent part of a national technology research programme

An important question concerns the pro's and con's to guiding principles for research, like for example the German principle about 'inherently safe nanotechnology'. The role of guiding principles is known in research and innovation and also in relation to environmental potentials (Petschow, 2005). However, it is not clear what kind of guidelines could provide guidance and what kinds are so general that nobody can be against them and no guidance therefore is gained from them.

Dialogue and vision building around the future development within the three technology areas could get inspiration from the plan of the Dutch Rathenau Institute's for dialogue around five possible near-future applications of nanotechnology in order to make the discussion about nanotechnology more concrete and involve more stakeholders in dialogue around the pro's and con's of nanotechnology (Van Est & Van Keulen 2004). It could also be worth learning from the ongoing UK project about upstream and early public involvement in nano research conducted by Lancaster University and Demos based on ethnographic research among nano researchers and dialogue activities between researchers and citizens seen from a governance point of view (Grove-White et al 2004). Also the Dutch experience with constructive technology assessment (CTA) as part of the national nanotechnology programme is worthwhile considering (Rip, 2004).

6.6.3 Environmental screening of research proposals

Environmental screenings of research proposals is also a measure that should be considered. However, such screenings are only valuable if those evaluating the proposals agree in the importance of these aspects *and* are able to assess these aspects. Some of the earlier Danish experiences within food technology and biotechnology research based on a request for applicants to address aspects of the impacts on environment, health and safety have not shown too promising results. Many researchers chose not to address the issues and the evaluators consequently did not find the aspects important enough to let these aspects influence the priorities and decisions made. The experience with the present demand for addressing socio-economic aspects in EU research applications has neither been too promising either, as many of the technical domains have addressed these issues rather superficial. One reason may be the lack of environmental and health knowledge among evaluators of the proposals, but others relate to disagreements with the priorities and the very basic difficulties in assessing these aspects in the very beginning of a new field of research. The earlier described dialogue processes could also be applied in the screening of research proposals.

6.6.4 Environmental assessment as part of research

Environmental screening of research proposals is one thing, while environmental assessments as part of research are something else. Such assessments can be part of all three types of research (policy research, technology research, environmental research). So-called 'integrated environmental assessment' is suggested in the EU nanotechnology strategy and in the Danish nanotechnology action plan. The idea could also be worth-while exploring within the ICT and the biotech area, while building on the experiences from the Danish technology assessment activities of ICT and biotech in the 1980'ies and 1990'ies.

An important aspect of the assessment of environmental aspects of technology concerns the structure of the research funding schemes and the organisation of the environmental research as integrated or independent of the technology research: Should the funding for environmental research be given independent of the technology research? Should the environmental research be organised as an integrated or an independent activity? Environmental researchers being part of a technology research group or department could, on the one hand, develop trust in the relation to the technology researchers and enough proximity to the research process and the research subject to allow for detailed assessments. On the other hand, integrated environmental research capacity without independent funding could run the risk of becoming too close to and too dependent of the technology researchers. The environmental researchers could be afraid of preventing patenting as a possibility by pointing to environmental risks of a certain material, process etc. or by presenting the research to external stakeholders for dialogue about environmental aspects. This dilemma would become even bigger, if the environmental researchers do not have their own funding. It is important to follow and learn from also foreign experiences with the organisation and the funding of policy research and environmental research. At University of Cambridge a researcher within sociology of technology is employed within a nano research group. The Dutch constructive technology assessment activity within the national nanotechnology programme is organised as an independent, but integrated programme. The CTA programme organises their own projects, but in connection to activities within the national nanotechnology program.

Furthermore, the competencies needed for such assessments are complex and could probably not be built within the single research organisation. All in all this points to the development of some independent capacity for assessment of societal aspects, including environmental potentials and risks of the three technology areas. A Danish environmental research capacity should also enable absorption, assessment and mediation of research on these issues from other countries.

6.7 Integration of environmental aspects in policy support for strategic innovation

The integration of environmental aspects into strategic innovation policies emphasises the creation of new paths of development and bringing new technologies to real life test. Instruments include:

- The support for combining technologies into products within specific fields of application whereby the environmental impacts better can be identified and assessed and realistic user conditions confront the technologies.
- The integration of environmental concerns into the innovation processes at the earlier stages of laboratory and prototype developments are important to assure that these aspects are being part of the creation of development paths shaped in these processes.
- The support for market development through combinations of regulation of potential application fields, support for demonstration projects and network activities involving potential suppliers, customers, knowledge institutions and intermediaries.

The new “High-technology Networks” and “Innovation Consortia” instruments launched by the Danish Ministry of Science, Technology and Innovation could be an option for targeted action towards eco-innovation for all three technology areas.

The Danish experience with development within wind power and organic food as areas of eco-innovation show that it is possible to develop new, more sustainable development paths within an application area in competition and cooperation with existing well-established trajectories. Such path creation demands a combination of reshaping existing institutions, competencies and regulatory mechanisms etc., and developing new institutions, competencies and regulatory mechanisms etc. The experience with the regulation of wind power and organic food also show, however, that there are limitations to the regulatory capacity of the market if the development of the market is not supported by systematic public procurement, development of standards, support for research and development, competence development and restrictions to the competing technologies and products. The following paragraphs discuss some application fields related to each of the three technology areas, which could be considered as themes in future planning of innovation programmes.

6.7.1 ICT

Environmental application of sensors plays today not a significant role in the development of sensors. A stronger development within this area seems to demand more governmental regulation of environmentally important industries in order to develop a stronger demand for sensors for collection of environmentally relevant process information.

There is also need for more focus on environmental potentials and risks in the development of pervasive computing components and products, since the present paradigms neither seems not to focus on eco-potentials and nor on the environmental wastes and emissions and radiation problems related to pervasive computing (intelligent products) and applications. Potential problems which need to be addressed are products, which are manufactured as throw-away products (often called ‘disposable products’), products which are difficult to dismantle, and products with a short life time because the software is not updated. There is need for support for innovation in the interaction between product, user and organisational and societal context in order to support the development of more eco-efficient use patterns. Besides this, there is need for research in the experience so far with intelligent products and the impact on eco-efficiency. Such research should develop more knowledge about the shaping of use patterns as an interaction between ICT-based products, user and context and thereby develop more knowledge about possibilities and limitations to eco-potentials in intelligent products and applications.

The increased integration of ICT-components into products could imply further pressure on the systems for handling of electronic waste, since there is no sign of total substitution of hazardous materials from this kind of products, although lead is expected to be substituted during the coming five years or so due to the RoHS directive. Strategies for effective enforcement of the RoHS directive for products for the domestic market, for export markets, and for imported products

The risks from increased electromagnetic radiation due to increased wireless communication and electrical fields calls upon demands to electronic equipment and components and ongoing assessment of the amount and kind of radiation in homes, workplaces, schools and the public space.

6.7.2 Biotechnology

There are still potentials in the development of the industrial applications of enzymes for substitution and reduction of the use of hazardous chemicals and enhanced resource efficiency in a number of industrial processes. In order to support the uptake of such enzymes there is need for regulation of chemical substances which the enzymes are supposed to substitute or optimise the use of, support to small and medium-sized enterprises’ uptake of enzymes and restrictions on resource consumption.

The project’s policy workshop showed the need for more dialogue about different scenarios for the role of bio-materials from agriculture and food industry in a future energy supply scenario based on renewable energy sources.

Reservation surrounds the use of genetic modified micro-organisms for bioremediation. Support for the development of more knowledge is a prerequisite for in-depth assessment of the potentials.

6.7.3 Nanotechnology

Nanoscience is in a critical phase of materialising into nanotechnology, but the scope and uncertainties are high despite major investments globally. Undertaking innovations in this area is therefore currently associated with much risk and well as fairly long term perspectives making it difficult to attract investors and industry.

Special consideration should be made on how to promote the industrial up-take of nanoscience which today is weak and in many cases only emerging; both in relation to creating cooperation with existing industry and promoting start-ups.

Further action could be to

- *Illuminate the business potentials and scope of eco-innovations* related to nanotechnologies so as to make both researchers, industry adn investors more interested, competent and attentive
- *Build environmental competencies* in the nano research institutes but perhaps more interestingly connected to the nano centres. Stronger linkages with environmental researchers, - experts and –industry are needed. It should overall be considered how to organise the nano knowledge production in Denmark most efficiently to achieve both a high innovative capacity generally as well as on eco-innovation and how the new suggested strengthened Danish nano centres feed into this. It should be considered how environmental competencies could be linked up to these if a nano eco-innovation strategy is to be pursued. A national think tank or environmental nano network could facilitate a take-off for such a strategy.
- A steady *long-term commitment from the authorities* may pull in a viable interest in the nano eco-potentials among the different stakeholders in the innovation system. Visions, targets and long term environmental regulation could promote the creation of new markets for pre-commercial nano technologies with an eco-potential.

6.8 Regulating areas of application in production, trade and consumption

Technology applications within environmentally important product and consumption areas could be influenced in a more environmentally friendly direction by identifying and regulating the impact of driving forces and the institutional regimes determining the use of materials, production processes, products etc. If mature and market introduced technology applications with 'green' potentials are not realised under present market, production and user regimes more stringent regulatory policies and standards could provide a difference. A sector or product domain approach may be needed in stead of a technology approach. Some application areas are discussed in relation to the environmental aspects identified in the analyses of the three technology areas.

The analyses of ICT- and biotechnology have pointed to mature and market introduced technologies, which are not having a sufficiently high uptake. In relation to nanotechnology regulation of applications is not yet a key instrument considering that most of the identified eco-potentials are pre-commercial. It is also very difficult considering the very wide general purposefulness of many of the nanotechnologies, i.e. the application areas are impossible to delimit. In specific cases, e.g. new types of energy efficient lighting or hydrogen cars, regulation of the application could be feasible, but at a later stage .

6.8.1 Regulating eco-efficiency and substitution of chemicals

ICT-based tools are often highlighted as enabling better planning and management of environmental aspects due to the possibility of collecting and processing more data. However, experiences from the application of such tools seem to show that the environmental potentials often are limited.

ICT-based tools for environmental management systems do not 'automatically' enable a better management of environmental aspects in industry and other organisations and might even prevent effective environmental management because the ICT-tools sometimes are supposed to work more or less by themselves. If better environmental management should be achieved there is need for stronger and more dynamic governmental regulation of businesses and public institutions and support for the development of the environmental competence through development of the internal relations between management, designers, manufacturing, sales and purchase etc. and the environmental staff, and between the industry etc. and suppliers, customers, governmental authorities and NGO's. Such initiatives could create a development of ICT-based tools, which together with other initiatives can enable better develop environmental management

Also the development of new, more environmental friendly paradigms for products and processes seems to depend less on ICT-based design tools than on development of the dialogue between stakeholders internally in a company and externally with suppliers and customers. For solvent-based chemical processes ICT-based eco-oriented process design tools are available, but are not in widespread use.

ICT-based process regulation and control is used in many industries. This kind of process regulation and control can also be a way of reducing environmental impact if the process regulation and control is focused on reduction of resource consumption, reduction of emissions of pollutants etc. Governmental regulation of industry in terms of demands to emissions and wastes combined with increased prices on resources etc. and support for competence development could encourage industry to focus the process regulation and control more on environmental aspects, including substitution of hazardous chemicals through a more widespread use of for example enzymes.

6.8.2 Transport, logistics and mobility

The amount of transportation of persons and freight is depending on a number of socio-economic changes that has very little to do with the development of ICT-equipment for transportation and logistics. The amount of private transport depends on for example the costs of housing and living in areas near the workplace of families and the prices on public transport and fuel. The amount of freight transportation is depending on the amounts of goods produced and the globalisation of industry and trade. Telework might contribute to some reduction in transportation, but might also enable more transportation, since it is now possible to work more efficient way from the workplace when for example participating in conferences, or visiting other facilities in a company. Hybrid cars with fuel engines and electrical engines or batteries building on complicated IT-based controlling of the combination of the different engines could give significant improvements in fuel efficiency. However, due to the present development strategies in the car industry and the tax system on vehicles and fuel the market penetration of these types of cars is modest.

One way among a number of possible measures to regulate the transport sector could be increased prices on fuel. Another could be to establish systems of road pricing or road tolls in areas where alternative and more environmentally friendly transport solutions exist as alternative to the existing systems and their expansion. While some aspects of e-business may have some advantages concerning distribution of software products (because they can be distributed electronically) it could lead to more transportation based on the distribution of small batches of physical products, which might also be regulated via higher prices on fuel or other means of regulating the efficiency of commercial transport of goods. In similar ways regulation of transportation may also support the further development and implementation of programmes for optimisation of transport logistics.

6.9 Summarising: Recommendations integrating future environmental and innovative aspects of ICT-, bio- and nanotechnology

6.9.1 Introduction

The development within the three technology areas hitherto and the identified probable future trends introduce issues concerning environmental potentials and risks, including potentials and risks related to use, wastes and emissions of hazardous substances and materials. The following recommendations aim at high quality environmental governance in the development of the three areas, so that issues of societal needs and environmental potentials and risks are addressed within planning and management of research, innovation and technology applications.

The recommendations are structured within the headlines

- **Environmental governance**
- **Guiding research and research policy**
- **Policy support for eco-innovation**
- **Regulating application areas**

A recommendation starts with a headline, which is the recommendation in a short form and concrete initiatives are proposed afterwards. Some of the proposals starts with some general proposals addressing all three technology areas and ends with proposals addressing each of the three areas.

The recommendations suggest roles to a broad variety of stakeholders, like research and innovation institutions, businesses and business organisations, governmental authorities, and consumer and environmental non-governmental organisations. The Ministry of Environment and Ministry of

Science, Technology and Innovation are seen as important governmental authorities in the planning of the implementation of the recommendations.

The status for each of the three technology areas are summarised in table 6.1

Table 6.1. Summarized status for the three technologies

ICT:
Environmental potentials play some, but not significant, role in the development and application of ICT-technology. Furthermore, new risks might be introduced with the increasing development within pervasive computing and wireless communication. As ICT is applied within almost societal areas, the dynamics of ICT-development are very complex.
Biotechnology:
Environmental potentials play an increasing, but still small role in the development of white biotechnology (which the analysis primarily has focused on). Focus is especially on increased resource efficiency, substitution of chemicals and remediation of pollution.
Nanotechnology:
Nanoscience is in a critical phase of materialising into nanotechnology, but the scope and uncertainties, technically and environmentally, are high despite major investments globally. Undertaking innovations in this area is therefore currently associated with much risk and fairly long term perspective long term perspective making it difficult to attract investors and industry.

6.9.2 Environmental governance

Strengthen the environmental governance in relation to ICT-, bio- and nanotechnology

General proposals:

Strengthened environmental governance should aim at

- focus on environmental potentials and risks in research, innovation and applications related to the three technology areas
- high legitimacy of the societal problems and needs and the environmental potentials and risks addressed in research and innovation
- critical comparisons of environmental potentials and risks of the three areas with other environmental strategies

Strengthened environmental governance calls upon

- more, high quality participation of concerned and affected stakeholders in the planning, management and assessment of public and private research and innovation activities related to the three technology areas
- changes in the procedures in planning, management and assessment of public and private research and innovation to make this participation influential
- facilitation of dialogue between different types of knowledge and experience (environmental, ethical, technology etc.)

Economic support is needed for Danish researchers', governmental authorities', and NGO's continued national and international networking around experiences with environmental governance in relation to the three technology areas.

Supplementary proposals for the three technology areas:

ICT:
There is a need for continued discussions about the environmental aspects of ICT and how they are shaped in interaction with societal trends like globalisation, more intense everyday life etc. This is also important as ICT technology in the future might get embedded into many new products like textiles etc. Such discussions should enable analyses that get deeper than the metaphor of 'the knowledge society' as very knowledgeable and only having limited resource consumption.

Biotechnology:
There is need for more public participation in the shaping of the future research and innovation strategies for white biotechnology. This should ensure discussions that get deeper than the metaphor of white biotechnology as a 'clean technology' in itself, because it is based on biological materials and processes.

Nanotechnology:
There are rising public, governmental and scientific concerns about how nanotechnology may lead to new types of health and environment risks because of new types of materials and processes with new characteristics. Environmental risks have hitherto been neglected to a high degree in the nano community. Since nanotechnologies could undergo much change the next 5-10 years there is need for ongoing dialogues highlighting trends, visions and fears. Nanotechnology comprises many different scientific fields why there is a need for discussions focusing on the different types of nanotechnology.

6.9.3 Guiding research and research policy:

Stronger integration of environmental aspects in the guidance of research and research policy

General proposals:

It is suggested to develop

- Broad and strong stakeholder participation (e.g. through new think tanks) in the ongoing development and assessment of visions for the environmental focus (potentials and risks) in research related to ICT-, bio- and nanotechnology
- Strengthened dialogue between the Ministry of Environment and the Ministry of Science, Technology and Innovation about strategies for focus on environmental potentials and risks in the research programmes of the Ministry of Science, Technology and Innovation
- Use of Constructive Technology Assessment and Green Technology Foresight, including participatory and dialogue-based processes as tools in future research planning and research assessment in relation to ICT-, bio- and nanotechnology

- Development of funding strategies for research in environmental aspects of the three technology areas. The strategies should consider dedicated funding for technology assessment and technology foresight and for environmental research (potentials and risks), and integration of environmental aspects into technology research, both in relation to mature and new fields
- Development of strategies for independent assessment of environmental potentials and risks in research proposals
- Development of strategies for integration of environmental competence in technology research, combining development of environmental competence in technology research groups and development of independent environmental research capacity based on competencies within environmental science, engineering and sociology of technology

<u>Supplementary proposals for the three technology areas:</u>

ICT:
There is need for more knowledge about the role of ICT-based tools and technologies in the shaping of eco-efficient use patterns and in environmental management in order to develop more socio-technically based development strategies and paradigms for ICT-technologies. This includes:

- Research on the interaction between intelligent products, users and organisational and societal context in the development of use patterns and the environmental aspects hereof
- Research on the role of ICT-based tools in the development of environmental competence in businesses etc. in order to develop strategies for effective development and application of such tools as part of environmental management

Biotechnology:
More knowledge about the environmental aspects of biotechnology seems to be one of the prerequisites for future application of these technologies. This includes:

- Research on the environmental potentials and risks of bio-remediation of pollutants based on release of genetic modified microorganisms
- Research on the environmental risks related to release from chemical-producing plants
- Research on the health impacts of an enhanced use of enzymes

Nanotechnology:
The key barrier to nano eco-innovation is the lacking awareness and knowledge of nano-related eco-potentials and business potentials. It is difficult to get environmental funding for fundamental nano research, since this kind of funding tends to focus on more mature and immediate solutions. There is need for:

- A nano eco-innovation research programme and/or a technology platform based on the identified eleven nano research areas with eco-potentials

- Research on the environmental impacts of all kinds of nanotechnology, particularly the toxicity of nanoparticles and other nano materials, including development of the capacity to absorb and mediate similar research from abroad
- Further development of existing environmental assessment procedures which are not adequate for measuring and handling materials at the nano scale and build nano competencies in the institutions undertaking these.

6.9.4 Support for eco-innovation

Support eco-innovation based on pre-commercial technologies with environmental potentials

General proposals:

The support for eco-innovation should be organised through

- Strengthened dialogue between the Ministry of Environment and the Ministry of Science, Technology and Innovation about strategies for ensuring focus on environmental potentials and risks in the innovation programmes of Ministry of Science, Technology and Innovation, including the Danish High Technology Foundation and the Innovation Consortia tool
- Development of environmental and economic visions and targets for specific technology areas
- Support for development of prototypes and for demonstration projects
- Market development through development of standards and long-term environmental regulation of related chemicals, resources, competing technologies etc.
- Support for development of eco-innovation-oriented competence in research and innovation through integration of environmental competence and technology competence

Supplementary proposals for the three technology areas:

ICT:
There is a need for more focus on the potentials and limits to intelligent products and applications and sensors as elements in an eco-efficiency strategy. Furthermore, there is a need for strategies to ensure focus on hazardous substances and materials and radiation in the development of products and components:

- Support for innovation in intelligent products and applications, including pervasive computing, with focus on the interaction between ICT-based products, users and societal and organisational context in order to develop concepts and paradigms for eco-efficient use patterns
- Analysis of the perspectives in further development of sensors for environmentally oriented process regulation and control, including different types of governmental regulation, which can support the development and dissemination hereof

- Development of strategies for effective enforcement of the RoHS directive for electronic products and components for the domestic market, for export markets, and for imported products

- Development of demands to the radiation from electronic equipment and components, and from wireless communication. Ongoing assessment of the amount and kind of radiation in homes, workplaces, schools and the public space

Biotechnology:
There is a need for development of enzymes with eco-potentials for a broader variety of industrial processes. Furthermore, there is also a need for a strategy for the use of bio-mass as renewable resource:

- Encouraging development of enzymes for a broader variety of industrial processes through dialogue between potential manufacturers and users

- Development of short-term and long-term national strategy for the use of different types of bio-mass as renewable resource for chemicals, energy, materials etc.

Nanotechnology:
There is a need for considerations about how the industrial up-take of nanoscience can be promoted, through existing industry and through new start-ups. A central barrier is lacking environmental competencies in the Danish nano community and lacking nano competencies among environmental experts and industry and the weak linkages between these groups:

- A national think tank or environmental nano network should facilitate a take-off of a nano eco-innovation strategy

- Build environmental competencies in the nano research institutes or in connection to the new suggested and strengthened nano centres by employing or co-operating with environmental experts

Launch a Danish Green Innovation programme focused on key environmental themes and key product and consumption areas

- The programme should be based on a combination of measures directed towards research, innovation, potential application areas and governance.

- Competencies within eco-innovation, environmental assessment and consumption dynamics should be included.

- The planning of the programme should be based on dialogue among government, research and innovation institutions, business, and consumer and environmental organisations.

Strengthen the role of environmental concerns in the further development of ETAP

The Danish government should encourage and support

- A stronger link between the focus of the ETAP technology platforms and important environmental themes

- Inclusion of a broad variety of environmental regulation instruments as measures in the ETAP implementation
- Participation of consumer and environmental organisations in the development, planning and management of the technology platforms in order to develop their environmental scope
- Danish participation in and initiatives for technology platforms related to ICT, biotechnology, nanotechnology and chemistry

6.9.5 Regulating application areas

Remove barriers to the dissemination of technology applications with environmental potentials

General proposal:

Where mature and market introduced technologies with environmental potentials are not taken up by potential users sector and product domain regulation should make present market, production and user regimes more environmentally oriented.

Specific proposals for the three technology areas:

ICT:

- Encouraging the use of ICT-based process regulation and control more towards higher eco-efficiency through stronger governmental regulation of wastes and emissions and prices on substances and materials, and support for environmental competence development in businesses and governmental institutions etc.

Biotechnology:

- Encouraging more widespread use of available types of enzymes in industry for increased process efficiency and substitution of chemicals through stronger demands to eco-efficiency and use of chemicals, and support for the necessary technological and organisational changes connected to the uptake, including the challenges faced by small and medium-sized businesses.

Nanotechnology:

- Regulation of application areas is not yet a key instrument for nanotechnology since most of the identified eco-potentials are pre-commercial, but it could become relevant later for specific product areas, e.g. for lighting or hydrogen cars.

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7.1 Chapter 1-2

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