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Danish Nano-science and Nano-technology for 2025

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Type: A national technology foresight project with the purpose of anticipating the range and scope of nano-scientific and nano-technological development in Denmark over the next 20 years.

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Purpose

The purpose of this Technology Foresight on nano-technology was to provide knowledge regarding the scope for nano-scientific and nano-technological developments over the next 20 years, as a basis for the development of a cohesive, long-term policy for research, education and innovation in this area. The delivery of an action plan for Danish nano-science and nano-technology containing recommendations for the next few years was the most essential task in the project. The target group consisted of the Danish Ministry of Science, Technology and Innovation and the Danish system of advisory and grant-awarding bodies for research and innovation.

Why make it a National Priority?

The aim of the Danish technology foresight was to provide a sound basis for cohesive, long-term Danish policy on research, education and innovation. In large countries like the US, Japan and China, annual investments running into many billions of dollars are already being made across wide areas of nanotechnology. Denmark cannot match figures of that kind. Instead the intention has been to focus carefully on the implementation of targeted long-term initiatives where Danish economic and societal interests are clear and where Denmark enjoys particular research and industrial advantages and scope.

A few months after this foresight project started the Danish government announced the establishment of the High-Technology Foundation. The aim of this new foundation is to strengthen growth and employment by supporting strategic initiatives in high-level technological research and innovation such as nanotechnology, biotechnology, and information and communication technology. This government initiative attracted a lot of attention to the foresight study on nanotechnology, especially from research environments.

Steering Group

The project was undertaken by a Steering Group appointed by the Danish Ministry of Science, Technology and Innovation. The Steering Group had seven members and included representatives from nanotechnology industry, nano-science and social science. A team from Risø National Laboratory acted as methodological adviser and process consultant for the project. The Ministry of Science, Technology and Innovation provided the secretariat for the Steering Group.

Domain Classification

'Nano-technology' is defined as the ability to work at the atomic, molecular and supra-molecular levels at a scale of

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0.1–100 nm for the purpose of designing, manufacturing, manipulating and applying materials, components and systems with new physical, chemical and biological functional properties. These new properties emerge because of the small scale of the structures, and can therefore not be obtained in other ways. Integration with other scales of length and areas of application will often be essential to technological applications.

'Nano-science' is concerned with obtaining an understanding of 'fundamental phenomena, properties and functions at the nano-scale, which are not scalable outside the nanometre domain'. The domain was divided in three subcategories nano-bio-systems, nano-electronics & nano-optics, and nano-materials. These subcategories structured the main activities in the foresight process. The Steering Group was well aware that these necessary simplifications could require adjustment at a subsequent stage in the process.

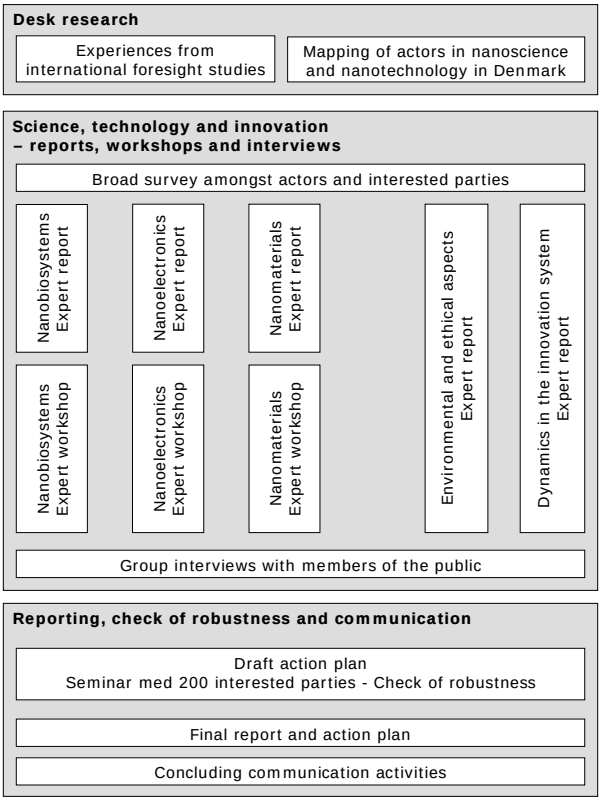
Hypotheses on Future Research and Industrial Impact

Nanotechnology is an emerging technology currently in an early, very exploratory creative phase. Wide industrial application lies many years ahead. Existing enterprises will have a future business interest in nanotechnology but a large number of new enterprises are likely to appear in the coming years.

Important building blocks in the Danish Nano-foresight process were hypotheses and statements about future research, industrial possibilities and consequences both beneficial and adverse of nano-science and nano-technology. These hypotheses and statements were systematically gathered from international technology foresight projects, Danish research environments and expert reports. They were discussed in subsequent workshops with attention to time-horizon, industrial scope, possible adverse consequences and policy implications. The process had the following key elements:

- Review existing foresight on nanotechnology,
- Map Danish nano-science and nano-technology,
- Survey interested parties,
- Commission expert reports,
- Hold workshops based on these reports,
- Analyse the dynamics of innovation in these fields,
- Survey hazards, environmental and ethical issues,
- Open interviews with members of the public.

The separate components and their interrelations and sequence are shown in the project diagram.



Findings and Lessons Learned

A basic concept in the process was the formulation of statements. The intention of the process design was to build the foresight on a systematic collection of statements or hypotheses about the scientific and commercial potentials of nanotechnology within a time horizon of 20 years. Subsequently, these statements/hypotheses were to be exposed to critical scientific discussion. The lesson learned was that the experts and actors were not familiar with the approach to thinking found in statements.

The expert papers show that the project group extracted 91 statements; a further 149 were extracted from responses to the internet survey. At the workshops, the statements were commented on, and a *real-time Delphi* questionnaire was filled in at the end of each workshop. The project concluded on 7 high-priority areas of technology. In the table below 32 statements are listed concerning applications of these 7 areas.

The concluding Action Plan mentions a number of examples of future nano-technological possibilities in seven high-priority technology areas. For most of the examples, consideration was given to the likely time horizon within which the

possibilities could be realized. This was based on the three Expert Reports, the broad survey amongst interested parties and the three workshops. It is important to emphasize that these are not predictions they are estimates and are intended as a tool to facilitate further discussions.

Nano-Medicine and Drug-delivery

- Intelligent drug delivery systems to monitor the state of cells in the body and report events such as cancer or small blood clots.
- Self-assembling nano-capsules made from functionalised polymers for cell-specific recognition, controlled release of active substance and concealment of the particle from the body's immune system.
- Biocompatible materials for drug delivery to applications that require slow release due to time for passage through the blood-brain barrier …
- New types of drugs based on nano-scale interactions and structural assemblies for example for the self-assembly of peptides and DNA strands into bioactive complexes.

Biocompatible Materials

- Development of nano-biotechnology for the repair of defective neurons by the application of electrically conducting nanostructures.
- Practical application of synthetic surfaces with biological properties for use in implants, prostheses and medico-technical equipment.
- Practical application of nano-designed surfaces to promote or inhibit adhesion for example of bacteria or algae in antifouling products.

Nano-Sensors and Nano-Fluidics

- NEMS (Nano-Electro-Mechanical Systems) for selective detection of specified molecules or cells, measurement of heat or binding energies …
- Development of very efficient, distributed sensor systems that combine CMOS and NEMS, that communicate using wireless technology and can be used in applications for environmental monitoring, process control, indoor climate control and traffic safety.
- Practical application of "lab-on-a-chip" systems based on nano-optics and nano-fluidic liquid handling systems for point-of-care diagnostics.
- Practical application of implanted sensors for monitoring infections …

Polymer Electronics

- Polymer electronics for displays and sensors integrated into packaging, for monitoring the condition and history of goods in transit and storage.
- Polymer transistors integrated into single-use equipment for analytical purposes in primary health care.
- Multicoloured plastic displays instead of liquid crystal displays.
- Polymer FETs or Field Effect Transistors for RFID tags
- Polymer electronics and optics for solar cell technology.

Nano-Optics and Nano-Photonics

- Fibres micro-structured in their longitudinal direction for use in high-power lasers for welding, light sources in large displays, super-continuum-generating units and optical communication systems,
- Compact, low-price nano- or micro-structured plane components with integrated optical circuits based on photonic band gaps with application to sensor systems and fibre-to-home technologies.
- New sensors and optical switches based on filling the fine structure in optical crystal fibres with liquids, coatings or liquid crystals.
- Signal processing based on PBG structures with built-in non-linear optical elements for modulation, wavelength conversion, four-wave mixing and optical conjugation.

Nano-Catalysis, Hydrogen Technology …

- The use of in situ, theoretical and other methods to create tailored catalysts and other functional nano-materials
- Chemical approaches to hydrogen storage based on use of methane, methanol or ammonia or in the form of metal hydrides and using new materials that incorporate nano-technology and nano-particles.
- New, cheaper, longer life SO and PEM fuel cells.
- Development and improvement of catalysts based on natural enzymes, efficient at low temperatures and pressures.
- Specific catalytic Nano-systems for the breakdown of pollutants in nature using pre-organisation of reagents, catalysis and product release.

Nano-Materials with New Functional Properties

- Alloys or ceramic materials that crystallise with very small grain size to give high strength and good workability for use in high-value products, from the micro to macro scale, such as implants and sports equipment.
- Nano-composites with greater properties than pure polymers for corrosion resistance, sound absorption, and ease of recycling.
- Functional products made from woven and non-woven polymer fibres
- Coatings with built-in chemical functionality obtained from nano-particles or a nano-structured topology.
- Block co-polymers for self-repairing surfaces.
- Nano-porous materials as filters in the food and drink industry.
- Thermoelectric materials with radically improved properties for cooling and energy production, based on nano-sized structures.

The Strengths and Weaknesses of Danish Nano-science

Danish strengths include:

- An internationally respected scientific research environments in quantum physics, biochemistry, optoelectronics, scanning probe microscopy and X-ray diffraction, and other fields or importance for nano-science,
- It is well-equipped for cross-disciplinary research,
- It has obtained an early start with the development of nano degree courses for research,
- It has relatively new and up to date production facilities.

On the other hand the Danish context suffers from the following general weaknesses:

- Denmark has a weak tradition for synthesis and technology development,
- Danish universities do not have a strong tradition for the commercialisation of research results or for the handling of patents and other IPR,
- Denmark has a weak entrepreneurial tradition,
- It suffers from a shortage of persons able to combine science and business,
- It does not have a tradition for large focused investment programmes,
- There is limited mobility between Danish research institutions and between the worlds of research and industry.

Envisioning Denmark as One of the World Leaders in …

The Steering Group's vision is that towards 2020 Denmark will be among world leaders in mastery of nanotechnology within selected areas. In selecting focus areas the Steering Group adopted the following criteria: a) Industrial and societal relevance. b) Research strengths and/or potentials. c) Global industrial, research or societal importance

Action Plan

A co-ordinated strategy for nano-technology needs to include a broad range of initiatives. The Steering Group provided the following recommendations:

- **Prioritise Technology Areas:** Support should be given to technology areas in which Danish enterprises and research environments are at the international forefront. High-priority areas of technology in non-prioritised order include:
  - Nano-medicine and drug delivery,
  - Biocompatible materials,
  - Nano-sensors and nano-fluidics,
  - Polymer electronics,
  - Nano-optics and nano-photonics,
  - Nano-catalysis, hydrogen technology, etc.
  - Nano-materials with new functional properties.
- **Create Interplay between Nano-technology Research and High-tech Industry:** Three types of initiative are expected to further nano-technological and nano-scientific research and development and appropriate links to industry. These are high priority Iinitiatives, visionary Iinitiatives and exploratory projects.
- **Establish Nano-technology Centres for Strategic Research and Innovation:** National investment should take the form of a concentrated programme that creates and supports entities with real international impact. It was recommended to establish two national nanotechnology centres for strategic research and innovation. These must have the critical mass to become international scientific and technological leaders in their field.
- **Increase Numbers of Graduates from Higher Education and Researchers:** Increased commitment to nano-science and nano-technology requires the availability of sufficient numbers of qualified MSc graduates and researchers. The training of graduates from higher education is an important mechanism for knowledge transfer between companies and research institutions.
- **Sensitise Danish Enterprise to the Future Role of Nano-science and Nano-technology:** Danish industry must be able to participate widely in the industrial revolution brought about by nanotechnology. Special efforts are required to provoke the interest of new and established enterprises in the possibilities offered by this domain.
- **Address Potential Hazards, in particular to Health, Environmental and Ethical Consideration:** The Steering Group recommended that grants be coupled to a requirement for nano-technology related risk assessment that covers production, use and subsequent disposal of nano-technologies as well as a comparison with alternative approaches. Denmark should urge the EU to take an active role in this area.

From Foresight to R&D Program

The foresight report was published and the specific recommendations were disseminated to individuals in the target group. Some recommendations have already been used in decision-making on R&D funding and have provided input to the strategic deliberation of publicly funded R&D institutions. Others are expected to be used for decision-making whereas some are being discussed in research councils and ministries. Others are being investigated and developed further.

Both the foresight process and the publication of the final report have created broader awareness and debate among researchers and decision makers about the hazardous aspects of nanotechnology. The relevant authorities and institutions are now examining these questions more seriously.

Sources and References

Technology Foresight on Danish Nanoscience and Nanotechnology. Action Plan. 2004, Ministry of Science, Technology and Innovation, 50 pp.
http://teknologiskfremsyn.dk/download/108.ano

Background Papers (in Danish)
http://www.teknologiskfremsyn.dk

Dannemand Andersen, P.; B. Rasmussen, M. Strange, J. Haisler: Technology foresight on nanoscience and nanotechnology. Forthcoming in Foresight (Emerald).