The Research Council of Norway

Stensberggata 26
Postboks 2700 St. Hanshaugen
0131 OSLO

Telefon +47 22 03 70 00
Telefaks +47 22 03 70 01

www.forskningsradet.no

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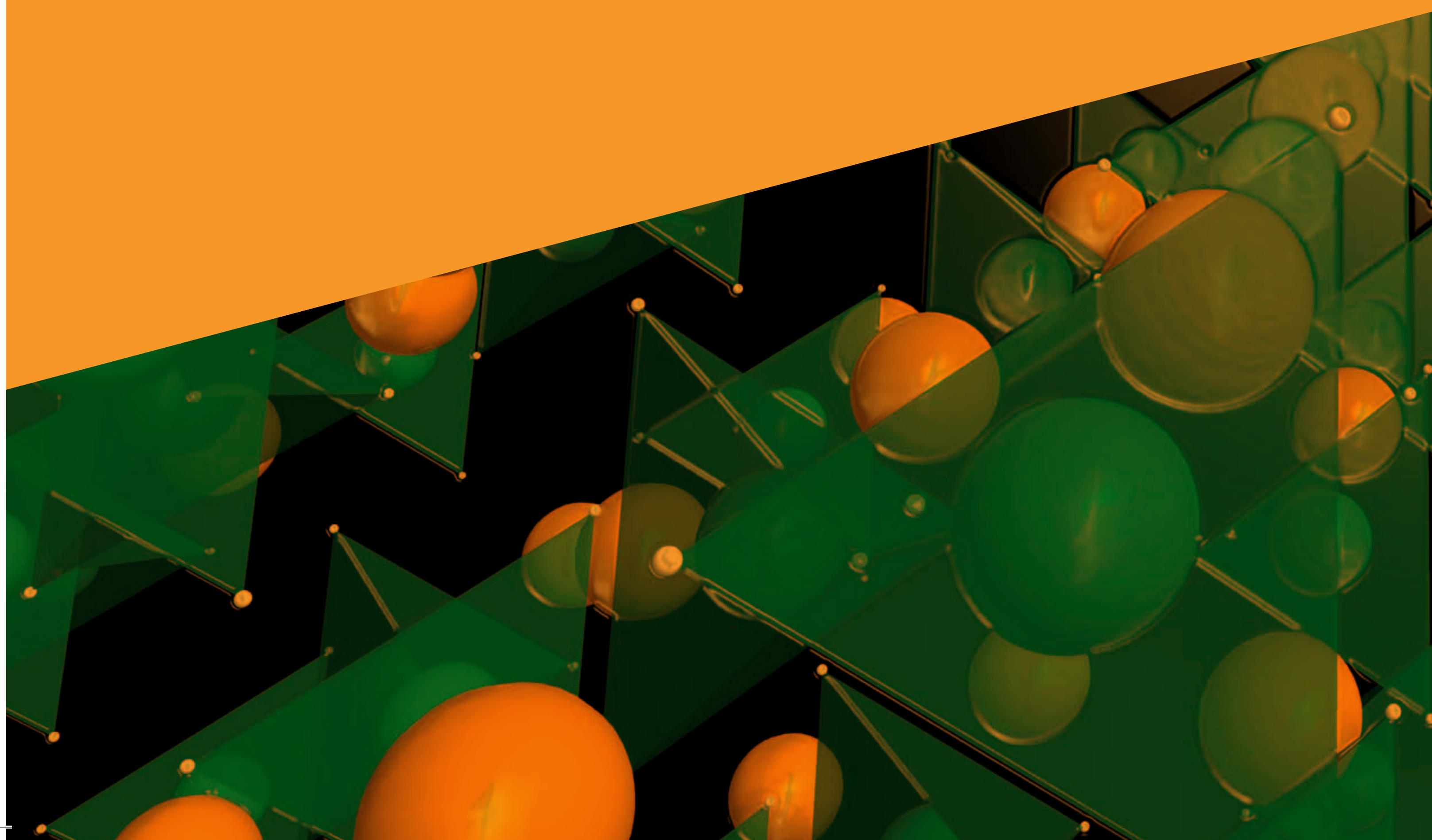
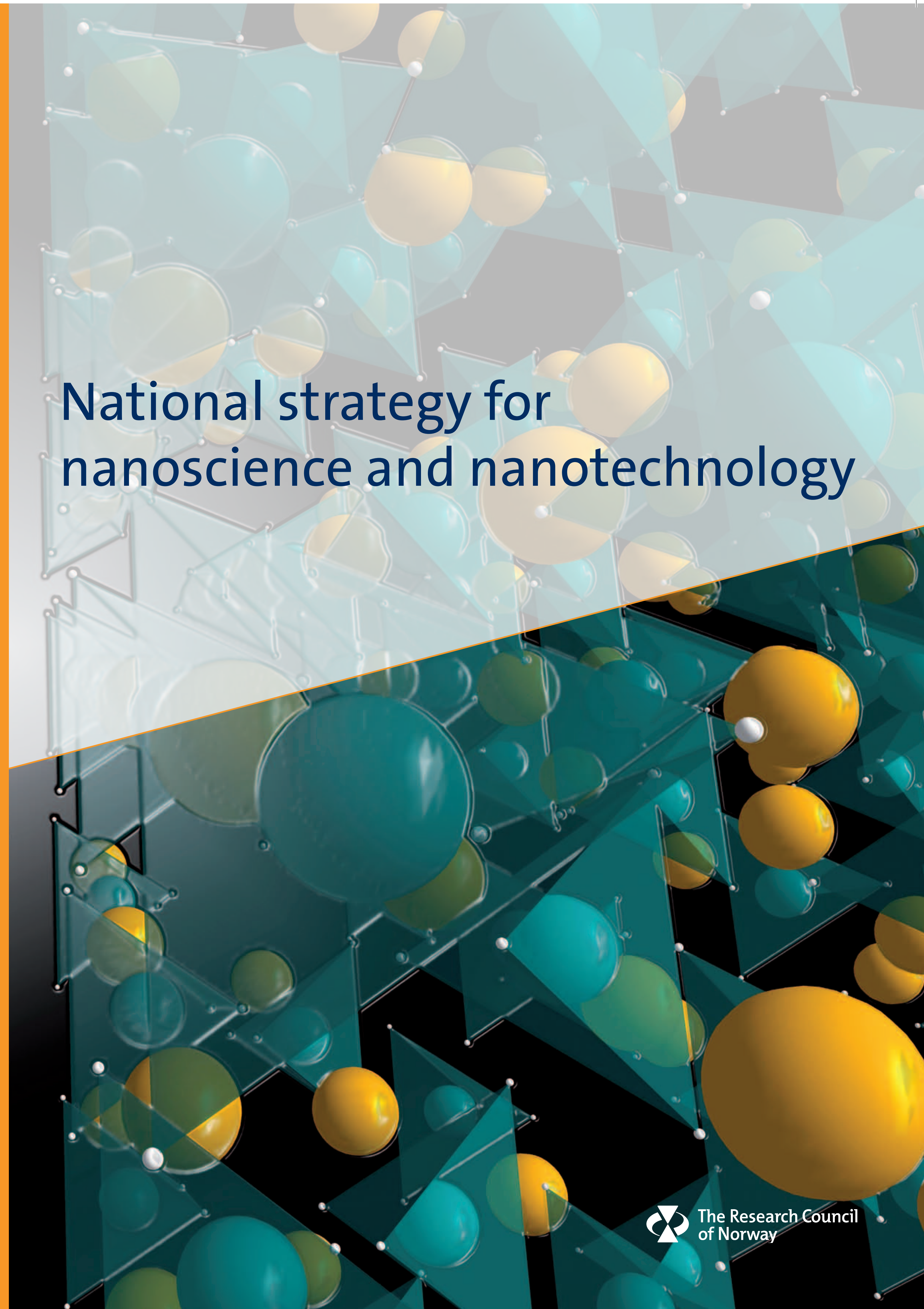


National strategy for nanoscience and nanotechnology



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National strategy for nanoscience and nanotechnology

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Content

Foreword

The strategy has been formulated by an independent working party appointed by the Research Council of Norway. The strategy discusses and provides advice about:

1. In which disciplines and research communities Norway, in the light of its needs and capabilities, should become an international leader.
2. Identification and prioritisation of new focus areas.
3. Measures to improve the recruitment situation within various discipline and sub-areas, including the need for further doctoral and postdoc fellowships, as well as other measures that will address the need for scientific expertise in the institute sector and in industry, and also in the professional disciplines.
4. Measures for further development of national coordination and division of labour between disciplines and research communities in order to achieve better utilisation of resources nationally. National coordination of laboratories and equipment should be emphasised.
5. Measures for enhanced mobility of Norwegian researchers, both nationally and internationally, and measures for increased internationalisation.
6. Measures for increased industrial growth in relevant industrial sectors in Norway, on the basis of increased cooperation between the university, college and institute sector and industry.
7. Research management and relevant measures for further development and improvement of today's situation.

The strategy has taken its point of departure in the Research Council of Norway's Foresight project "Advanced materials Norway 2020" [The Research Council of Norway 2005] and to a certain extent the Foresight projects "Energy 2020+" [The Research Council of Norway 2005(b)], "UTSIKT" [The Research Council of Norway 2005(c)] and "Aquaculture 2020" [the Research Council of Norway 2005(d)]. In parallel with this strategy, a strategy for mathematics, natural science and technology (the "MNT Strategy") has been drawn up [The Research Council of Norway 2006].

The working party consisted of:

- Professor Bengt Kasemo, Chalmers University of Technology, Gothenburg (chairman)
- Assistant Research Director Ralph W. Bernstein, SINTEF (ICT)
- EHS Manager Inger-Johanne Eikeland, Elkem
- Professor Mari-Ann Einarsrud, NTNU
- Professor Helmer Fjellvåg, The University of Oslo
- Professor Jan Petter Hansen, The University of Bergen
- Divisional Director Christina I.M. Abildgaard, the Research Council of Norway (observer)

The working party has been supported by a reference group consisting of:

- Professor Anja Boisen, the Technical University of Denmark
- Director Eva Dugstad, Institute for Energy Technology (IFE)
- Professor Vidar Hansen, the University of Stavanger
- Professor Henrik Jakobsen, Vestfold University College
- Director R&D Frank Karlsen, Norchip
- Senior Lecturer Unni Christine Oxaal, Norwegian University of Life Sciences
- Senior Engineer Ingrid Roland, the National Pollution Control Authority
- Professor Kenneth Ruud, the University of Tromsø
- Senior Executive Officer Roy Skulbru, Ministry of Trade and Industry (observer)
- Manager Tore Tennøe, the Technology Council
- Director Ellen Dahler Tuset, Norspace
- Director Oddvar Aaserud, Venturos

The secretariat has consisted of Researcher Ole Martin Løvvik from the University of Oslo, who has been the group's secretary, Programme Coordinator Dag Høvik and Senior Executive Officer Agnes Aune, both from the Research Council of Norway, Division for Strategic Priorities. In addition Senior Adviser Aase Marie Hundere has been a liaison in the Division for Science, and Advisor Tor Einar Johnsen in the Division for Innovation.

The Research Council of Norway would like to thank everyone who has participated in the preparation of this strategy. Through their enthusiasm and many inputs, the participants in the working party and the reference group have contributed to a very thorough report. We would like to thank in particular the chairman of the working party, Professor Bengt Kasemo, for his very positive and firm leadership throughout the entire process, and Researcher Ole Martin Løvvik, who has been an excellent secretary for the working party.

Oslo, November 2006

Arvid Hallen
CEO
Research Council of Norway

Anne Kjersti Fahlvik
Division Director
Division for Strategic Priorities

Summary

Nanoscience and nanotechnology (N&N) will lead to important changes that affect all parts of society. N&N is all about advanced and systematic control of materials on the atomic and molecular scales. The field is **generic**, will lead to value creation and new jobs in a broad range of industries and will create vital communities. N&N offers great opportunities for sustainable energy systems, enhanced energy efficiency and improved health services. Research into N&N will also make important contributions to a deeper understanding of and fundamental insight into the basic sciences of physics, chemistry, biology and mathematics.

Norway has a good point of departure for establishing internationally leading research communities within a number of N&N niches, based both on our natural resources, strong industrial sectors and existing research expertise. Scientific and technical developments are rapid, while Norwegian industry and society are showing increasing interest – the time to put N&N into high gear is now.

This N&N strategy identifies thematic priority areas, required expertise areas, tool platforms and the need for advanced infrastructure. **The four thematic** priority areas are based on a combination of identified Norwegian resources and competencies, and correspond to national priorities from the 2005 White Paper on Research: Energy and Environment, ICT and Microsystems, Health and Biotechnology, and Sea and Food.

The working party recommends an intense focus on six **expertise areas** be initiated: Materials; surface/interface science and catalysis; fundamental physical and chemical processes at the nanoscale; bio nanoscience and nanotechnology; devices, systems and complex processes based on N&N; ethical, legal, and societal aspects (ELSA) including health, safety and the environment. The strategy also recognizes essential **tool platforms** for N&N: synthesis, manipulation, and fabrication; characterization; theory and modelling. ELSA should be integrated into relevant projects and centres, and should be coordinated with similar research in other technologies.

MiNaLab/SMN in Oslo and NTNU NanoLab in Trondheim are by far the largest experimental installations for N&N in Norway. Interest is at the same time increasing at several other R&D institutions. The working party recommends the creation of two **national infrastructure centres** and a set of tool platforms. The national infrastructure centres and the tool platforms should be given appropriate resources to offer the entire R&D sector broad access to state-of-the-art experimental tools and methodological competence at an affordable price.

Expertise within some new areas must probably be imported in order to keep the desired pace. This involves systems for the financing of individuals, stimulation of excellent researchers to travel abroad and creation of tenure tracks in Norway. Excellent infrastructure and high scientific level in robust research teams will attract international experts as visiting researchers. **Internationalisation** should also be undertaken through networks utilising complementary expertise of the participants.

In additional to the usual projects funded by the Research Council, a new kind of **major project** should be initiated, where basic and applied research, innovation and contact with the industry are components of equal value. Partners from industry should be allowed to participate in these projects. Such projects require competent **research management**, and education in this field should be offered.

The strategy recommends that a **new research program** for N&N, materials, and integration be established within the Research Council of Norway. This program should also support research aimed at the thematic priority areas, in coordination with other programs in the Research Council. The program should also take care of the special needs of this new research field, through installation and operation of new and expensive infrastructure, following up important trends, and the establishment of internationalisation, national coordination, etc. It should also contribute to the promotion of N&N and the natural sciences, and contribute to the exploitation of results. The most natural option is considered to be that the new programme should be an expanded and strengthened version of the NANOMAT programme ("New Nano Programme") In the long run we can consider the establishment of a national council for N&N.

The budget recommends a financing level for N&N starting at NOK 140 million per year in 2007, increasing to NOK 250 per year in 2011, and then steadily growing to NOK 280 million per year in 2016. This is in accordance with the Norwegian Foresight project "Advanced Materials 2020".

Such an escalation will put Norway on the same level as comparable countries, and is a precondition of our being able to implement the ambitious goals of this strategy.

Vision:
Norway will become a leading nation within selected niches of nanoscience and nanotechnology. Through fundamental knowledge, advanced technology, and broad competence a strong basis will be created for increased value creation, new industry, and new knowledge.

Background

What are nanoscience and nanotechnology (N&N)?

Nanoscience and nanotechnology (N&N) have the potential to cause social changes on the scale of the Industrial Revolution. A special feature of nanotechnology is its **generic** character; it can affect almost all areas of society, and in many contexts has been described as the next industrial revolution [National Nanotechnology 2006].

The nano dimension covers chemical bonding, molecular and atomic phenomena in chemistry and physics; it also includes building-blocks and key elements of biological macromolecules and structures that in turn support gene technology, cellular biology and neuro-informatics. The broad description of the nano field shows that it permeates the natural sciences, medicine and technology, and thereby also industry and wealth creation. The report **demarcates** N&N from traditional disciplines and technology by means of the topics emphasised and through the scientific approach involved in understanding and exploiting phenomena that arise at the nanoscale.

Even today we are utilising a number of different products based on nanotechnology, for example as components for data storage, sunblock, catalysts for exhaust scrubbing, contrast agents for medical imaging, nanostructured paint with high scratch resistance and textiles from which dirt simply drops off. In the longer run, however, nanotechnology will affect everyone's daily lives, and the global market for new products is expected to be extremely large in the course of a relatively short time. Examples of coming products are cheap and very efficient solar cells, energy-efficient dwellings (smart windows, efficient and flexible lighting) and catalysts and materials for sustainable energy production.

Other product areas are based on technology taken from the electronics industry, such as efficient computers and high-capacity data storage, medical diagnostic methods and treatment (biochips), sensors for safety and comfort in cars, and monitoring of the environmental and industrial production.

Nanoscience opens the door to **radical scientific breakthroughs**. New phenomena may arise in consequence of the interplay between organised entities at the nanoscale. One example is supersensitive reading heads for magnetically stored data. The performance, stability and reactivity of nanostructured materials and components may scale new heights; nanotubes and nanocomposites may achieve a unique mechanical strength, nanoparticles may exhibit an extreme resistance to corrosion and nanostructured catalysts may yield a new degree of selectivity. The development of new methods means that we can now put together Nature's building blocks in a controlled and systematic manner. It is not until we have mastered this that we will really be operating with nanoscience and nanotechnology.

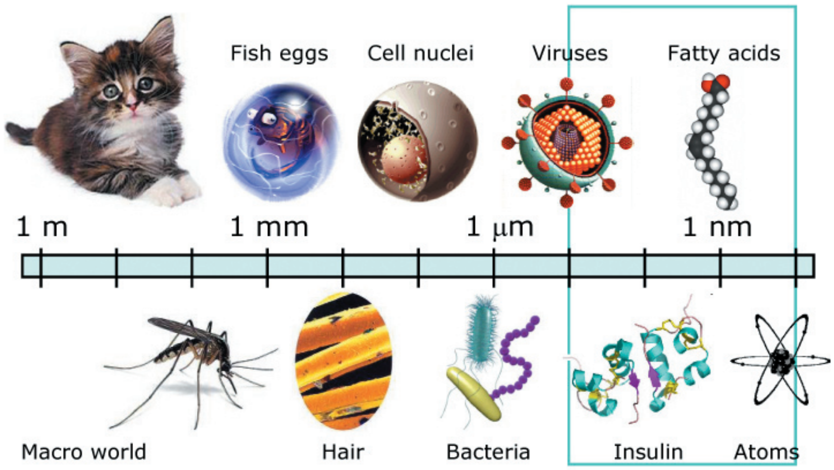
Nanostructured materials and components may be manufactured in two basically different ways: by miniaturising (top-down) or by building up from atomic building-blocks (bottom-up). The nano-products of the future will be produced by both methods. Miniaturisation of electronics and microsystems by the use of lithography, stamping and direct structuring is a top-down method. The same goes for grinding of powder to make nanoparticles, methods for "writing" of nanostructures and diverse etching techniques.

Nanostructures that are built up atom by atom, molecule by molecule or particle by particle, are a bottom-up method. The atoms, molecules or particles then constitute building-blocks (Lego bricks) that can be assembled to create specific nanostructures. Examples of bottom-up methods may be found in crystal-growing and synthesis on the basis of chemical methods and self-organisation.

Nanoscience is not a single discipline in the same way as physics, chemistry or biology. Rather, these established disciplines constitute a basis for nanoscience. Nanoscience demands a high degree of **interdisciplinarity** and convergence between disciplines. New insights are also expected in these hitherto under-researched interfaces.

In the same way, nanotechnology is not a single technology, but a collection of technologies, methods and materials that are on the basis of control and structuring at the nanoscale so as to achieve new properties and functions.

N&N encroaches drastically upon natural-science disciplines and social technologies, and will be crucial to **competitiveness** and **capacity for renewal** in the 21st century. N&N offers undreamt-of opportunities, but at the same time a responsibility for the management of new knowledge and new technology in the best interests of society and the community. New knowledge in the field of N&N will in the main be generated internationally (>99%). In addition to Norwegian R&D beeing able to make use of this knowledge, it is vital that Norwegian N&N rapidly finds competitive niches with potential for new insights and wealth creation.



Nanoscience and nanotechnology are defined to be in the scale from 0.1 to 100 nm (nm is defined in the box.) Here this is illustrated with familiar examples from biology.

- **Nanotechnology:** Exploitation of materials, structures, components and systems on the basis of nanoscience. In some contexts nanotechnology also embraces nanoscience, but here we use them as two difference concepts.
- **Nanoscience:** Measuring, describing, modelling and systematically manipulating and controlling nanostructures and dynamic processes operating at the nanoscale.
- **Nanostructures**: Materials, components and systems with a size between 0.1 and 100 nm.
- **Nanometre (nm)**: A millionth of a millimetre. The prefix nano is from the Greek for “dwarf” and means a billionth (thousand millionth). If a teaspoon of water could be spread evenly over a football pitch, the depth of water would be about 1 nm. Our nails grow about 1 nm per second, while a virus is about 100 nm across. At the nanoscale, phenomena and properties may be fundamentally different from what we find in the same materials, structures and systems on larger scales. The relatively broad definition of N&N above will be implicitly restricted to the topics treated in the report.

What is happening internationally?

- *Most industrialised countries are investing heavily in N&N, with rapidly increasing public research funding.*

- *The EU, Japan and the USA are the three biggest players, with intensive and extensive investment.*

- *Smaller countries are undertaking more focused and prioritising investment.*

In countries of different sizes and with a different degree of expertise-heavy industry, there are great and important differences between volume of and focus on N&N, see the figure on the next page. **Norwegian investment is modest**, even measured by population size. Several countries of a comparable size have much heavier investment, which tends to be reflected in their degree of innovation and creativity.

It is worth noting that **Ireland** and **Israel**, of comparable size with Norway, have the world's biggest public investment in N&N measured per capita [European Commission 2004(b); 2005(d)]. In Ireland this is the result of concrete recommendations in "Statement on Nanotechnology" [icsti040714] from the Irish Council for Science Technology and Innovation in 2004. The report lays particular emphasis on electronics, photonics, pharmaceuticals, medical technology, food production, polymers and plastics, plus construction materials. Ireland possesses a number of small and large companies that have, or are expected to have, a considerable level of activity in nanotechnology.

Global activity can be divided into four roughly equal portions: the USA, Japan, the EU and the rest of the world. The figure on page 9 illustrates how in the period 2000–2005 investment in N&N underwent a very rapid **expansion** phase, and has now reached a high level among the pace-setting industrial nations. Total public appropriations tracked one another closely in these regions, but there are nevertheless relatively large differences between how the investments are implemented. This is happening quickly, and countries like China and South Korean may soon become very important and set the pace.

The size of the country seems to determine the breadth of focus. The three big players the EU, Japan and the USA have solid activities on all fronts in N&N. The smallest countries, with Sweden and Denmark as obvious examples, have **concentrated** their investment in a few fields, but in addition have smaller levels of activity in several fields so as to maintain a minimum breadth [Nanoforum 2003].

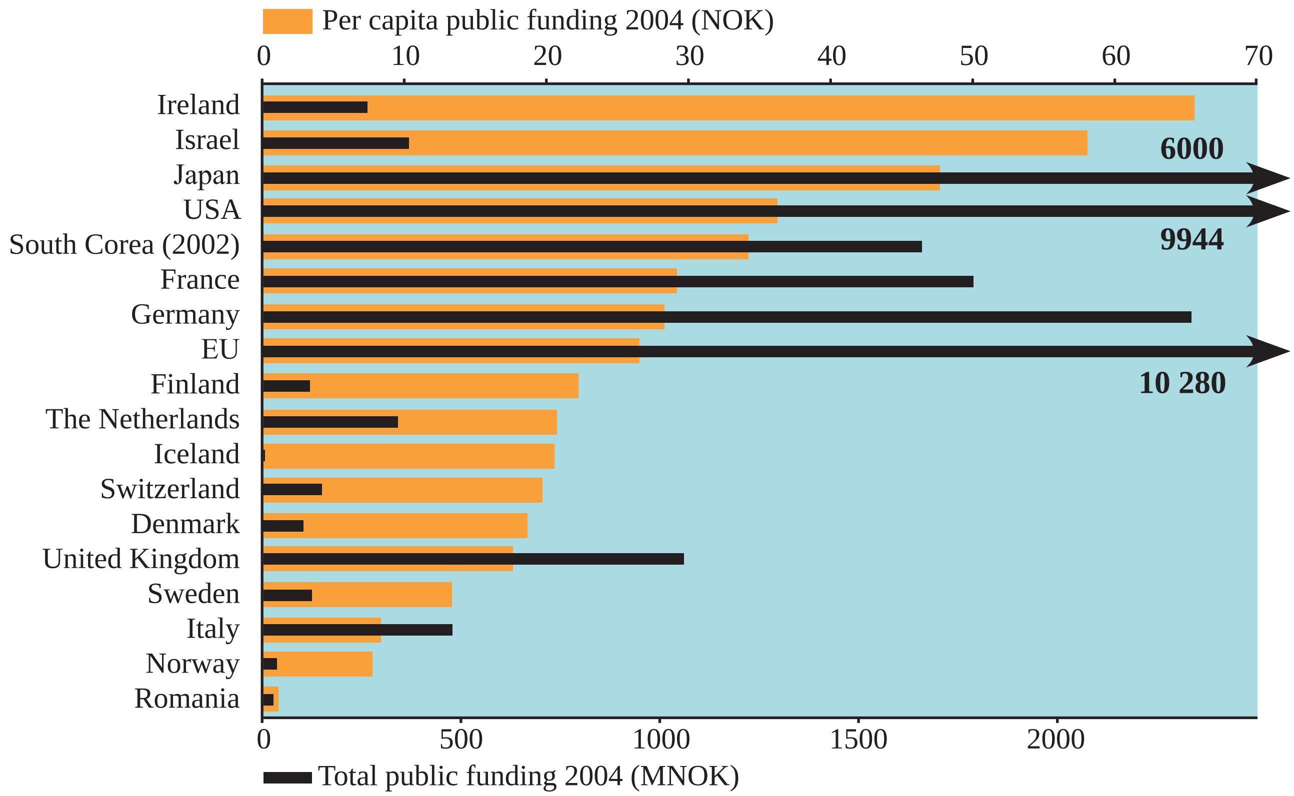
There are considerable differences between how applied the publicly-financed research is. The USA's nano investment has much more the character of **basic research** than the EU's, even if in its sixth framework programme the EU announced a heavier focus on fundamental nanoscience. This may be explained partly in terms of the fact that the EU has so far left large parts of the basic research to the individual member countries.

Another important difference is **industry's** investment in nano research. Here the USA again stands out, with by far the biggest level of investment in the world. This is reflected in the American ability to innovate. Half of all consumer products and business start-ups on the basis of nanotechnology now come from the USA [Nanotechproject 2006].

The Big Three: The USA, Japan and the EU

The USA
In 2005 they spent about USD 1,100 million on N&N via the National Nanotechnology Initiative (NNI), which coordinates most public programmes [US NSTC 2004, 2005]. The appropriations are channelled through individual researchers and teams, collaborating partners and major centres. The national Nano strategy designates concrete targets for the investment in R&D, technology transfer and prosperity development, education and infrastructure plus a responsible development of nanotechnology. The USA wishes to be **the world leader** in most N&N fields, and most of the seven main components of the programme are generic: Fundamental phenomena and processes at the nanoscale; nanomaterials; components and systems at the nanoscale; instrumentation, measurement technology and standards; nanofabrication; major research installations and social dimensions.

The main goals of the programme are:
- to maintain world-class R&D with a view to exploiting the full potential of nanotechnology
- to facilitate technology transfer to products for economic growth, new jobs and social utility
- to create resources for education with corresponding advanced infrastructure and tools
- to support a responsible development of nanotechnology

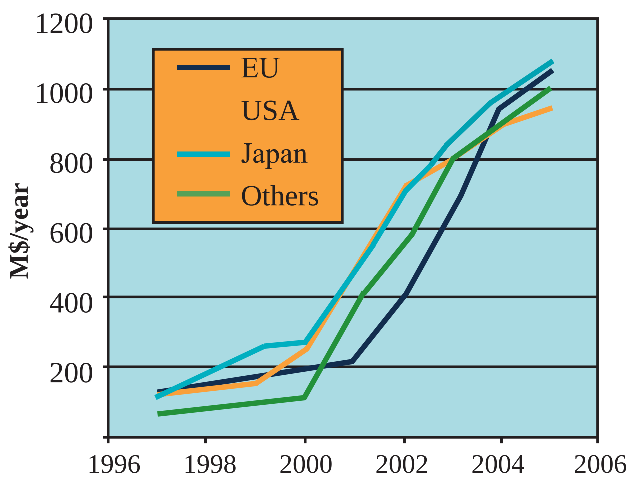


Public funding for nanoS&T per capita (NOK/year) and in total (millions of NOK/year). [European Commission 2004(b);2005(d)]

The USA's public investment, therefore, emphasises the entire chain from education, basic R&D to industrialisation.

Japan
In the five-year investment plan for science and technology from 2001 [National Institute 2001], nanotechnology and materials are defined as one of four main areas, together with ICT, life sciences and environmental technology. In the same way as the USA, Japan is prioritising basic research, and has national funding of advanced scientific equipment, laboratories for synthesis and fabrication at the nanoscale in dedicated national N&N centres [Japanese Council 2005, NISTEP 2005]. The operation of advanced laboratories is subject to **national coordination**. Innovative basic technology that creates fertile soil for new industry is a priority area. For example, the New Energy and Industrial Technology Development Organization (NEDO) emphasises nanotechnology related to materials, materials manufacture, measurement technology, biotechnology, ICT and nano-production technology. Exchange of researchers and international research collaboration is another priority area.

The EU
The objective for the EU's sixth framework programme (2007-2013) in "Nanoscience, nanotechnology, materials and new production technologies (NMP)" is to "*...strengthen the competitiveness of European industry and ensure a transition from a*



Public funding of nanoS&T in EU, Japan, USA and the rest of the world. The numbers include both new and redefined funding.

resource-intensive to a knowledge-intensive industry, by creating new knowledge with epoch-making breakthroughs for new applications in the interface between different technologies and disciplines" [European Commission 2005].

The EU has not established N&N as a separate thematic priority area; N&N is a central part of the NMP programme, but at the same time is heavily funded through the Information Society Technology (IST) programme. In 2005 the funding of nanotechnology in the sixth FP came to about EUR 470 million, in which the NMP share was about 44%, while the IST accounted for about 38%. Approximately the same level is expected in 2006 and 2007, with an increase of investment in N&N towards the end of the sixth FP. In addition, N&N will be included in eight of the nine thematic priority areas in the EU's seventh framework programme. The main motivation is **technology needs** [COST 2005; European Commission 2005; 2005(e)].

Our neighbours

Denmark

Denmark's strategy for N&N from 2004 [Ministry of Science 2004] focuses on applications. The vision is "*... to be among the absolute best countries in the world – in selected areas – in mastery and conversion of nanotechnology into industrial applications, increased growth and employment – and to satisfy major social needs.*"

The prioritised technology areas have been chosen on the basis of their **industrial and social relevance** in addition to research strengths and/or potential. The prioritised areas are nanomedicine and drug delivery, biocompatible materials, nanosensors and nanofluids, plastic electronics, nanooptics and nanophotonics, nanocatalysis, hydrogen technology and similar, plus nanomaterials with new functional properties. The report recommends the establishment of two national nanotechnology powerhouses, which shall be international scientific and technological leaders in their fields. This strategy is in the process of being partially implemented, with the establishment of a powerhouse at the University of Aarhus and subsequently at the Technical University of Denmark in Copenhagen.

Sweden

Sweden has no paramount national strategy for N&N, and has in the main elected to **integrate** N&N into existing research instrumentalities. In 2001 a network of Swedish researchers in the field of N&N submitted "Strategy document for a Swedish Nano Network" [Swedish Nano 2001]. The document has so far not been followed up by the spending authorities. The plan designates the six areas which are functional materials, nanoelectronics, quantum physics and quantum phenomena, molecular electronics, nanobiology and nanomedicine plus nanotools. Sweden has no research programmes dedicated to N&N, but a long series of projects and research consortia have been funded by the Foundation for Strategic Research centrally for N&N [Stiftelsen 2000; 2001]. In addition some projects funded by the Science Council, Vinnova, the Knut and Alice Wallenberg Foundation and other funding sources.

Finland

In Finland's first investments in nanotechnology in the period 1997–1999, the responsibility was divided: the Academy of Finland had the responsibility for more theoretical basic projects, while TEKES had the responsibility for innovation-oriented and user-managed projects. The **twofold investment** was also meant to fill the gap between the two kinds of research. [VDI Technology Zentrum, report March 2004].

In the period 2005–2009 Finland launched a new nanotechnology programme – FinNano – with the Academy of Finland and TEKES as the main players on the programme side. About EUR 70 million has been invested, of which EUR 50 million is to be channelled through TEKES. [The 1st FinNano Annual Seminar 2006, presented by Dr. Markku Lämsä, TEKES]. The foci of the TEKES projects are "innovative nanostructured materials", "new solutions for nanoelectronics" and "nanosensors and actuators".

Through the Academy of Finland, EUR 9 million has been earmarked for research projects in "direct self-assembly", "functionality in nanoscale" and "properties of single nanoscale objects". At the same time, the Finnish Ministry of Education is granting EUR 24 million direct to the development of university education and research, creating centres of excellence and funding infrastructure.

Finland has several strong scientific communities in the important thematic priority areas at the big universities in Helsinki, Jyväskylä, Turku and Tampere, and the VTT research institute.

Why should Norway invest in N&N?

- *N&N lays the generic basis for new technologies and large wealth creation. Norway can exploit this potential to establish new wealth creation that is not related to raw material production.*

- *N&N is probably the key to sustainable energy supply, which can give Norway as an energy nation the opportunity to become the world leader in the field of N&N for the energy systems of the future.*

- *Norway must develop its knowledge in parallel with other countries' programmes so as to be able to participate in, understand and make use of the technological and societal changes that will result from developments in N&N. Furthermore in order to consolidate industry, secure expertise in important social technologies, and to seize new opportunities.*

- *N&N is still at an early stage with major potential for small countries to assert themselves and particularly within niches where competitive edges can be constructively exploited.*

The ambition of the **research white paper** is that Norway should become a leading research nation in new technology, expertise and knowledge [UFD 2005]. Research in the four thematic priority areas Energy and the Environment, Food, Ocean and Health must be given priority. New materials and nanotechnology are one of three prioritised technology areas that support the thematic priority areas and shall contribute to strengthening basic research and innovation. N&N will have great significance for the Research White Paper's other technology areas ICT, materials technology and biotechnology. The Research Council's Foresight report on materials [the Research Council of Norway 2005] points out that "materials and nanotechnology are one of the keys to Norway becoming a nation at the head of the international pack as regards technological expertise and knowledge."

Most industrialised countries have already created strategies and programmes for N&N. They expect that nanotechnology will contribute to considerable **prosperity development**, inter alia via increased wealth creation and new jobs. The same perspective applies to N&N in Norway. In line with the White Paper on Research the proposed strategy will reflect how Norwegian N&N supports the national prioritisations and builds the necessary expertise basis for new wealth creation.

Here come some examples of research challenges that demand N&N. N&N in **energy and the environment** will contribute to the development of sustainable solutions [Nanoforum 2004; Institute of Nanotechnology 2005; Masciangioli 2003] in a world with growing energy needs. Nationally, refining and conversion of natural gas, water purification and CO_2 handling are important topics. New generations of catalysts, membranes and absorbents will contribute to more eco-friendly and energy-efficient process industry. The clean energy systems of the future depend to a high degree on materials and nanotechnological breakthroughs. Solar panels with much better energy-efficiency, materials that make the vision of the "hydrogen society" possible and solutions for energy economisation (light-emitting diodes, superconductors, accumulators) are some of the examples of how N&N can contribute to considerable technological improvements and breakthroughs.

The dimensions of the smallest transistors in **computer technology** are under 100 nm [Intel 2006]. The computer chips of the future must deal with quantum effects when size shrinks further. New fundamental principles (quantum computation), new forms of rapid or permanent data storage media and associated reading and writing heads, optical communication, broadband technology, flatscreens and flexible monitors (electronic paper) will be developed on the basis of N&N. Futurology suggests that sensors will be integrated into a number of societal technologies. There is talk about a coming instrumentation society that will base itself on distributed sensors, actuators and energy harvesting in order to achieve autonomous (self-controlled) systems. Nanostructured functional materials are key components here. Present-day microelectromechanical systems (MEMS) will steadily develop in the direction of nanoelectromechanical systems (NEMS) in these areas.

Nanotechnology will, together with biomaterials and medical technology, be the key to many opportunities in **health** [Morrison 2003; VDI 2005]. In particular, the interplay between one or more of these technologies will be important. Bionanotechnology, which lies at the junction between several technologies, will enable a more reliable and efficient diagnosing and drug delivery, and new methods of treating injuries and physical handicaps.

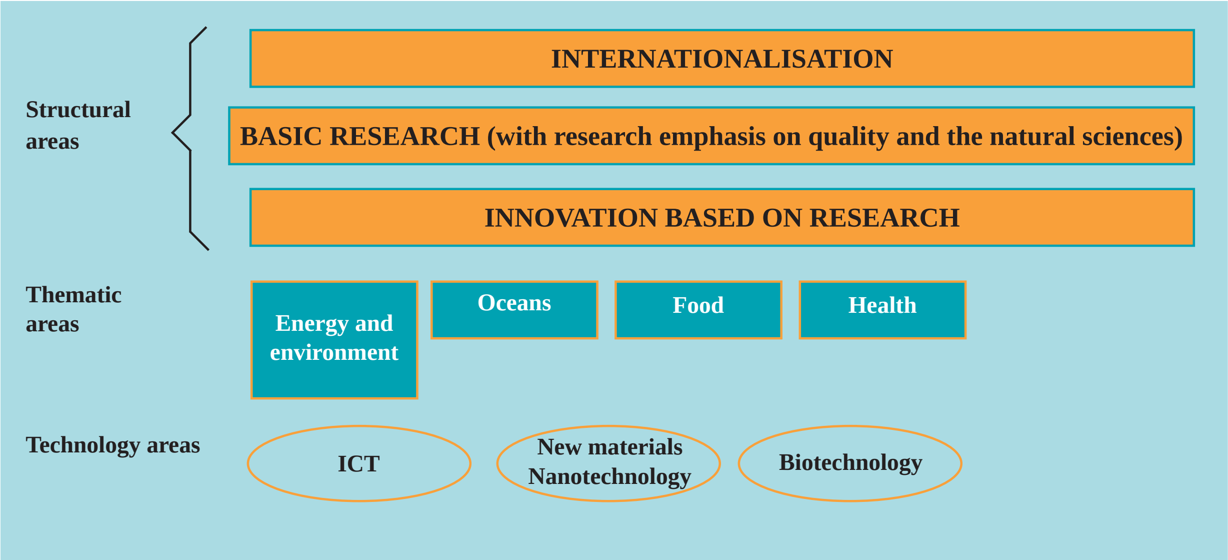
Developments will occur along many axes. Increased knowledge of pathology may lead to good pre-clinical modelling systems for characterisation of mechanisms and processes and testing of drugs. Diagnostic and visualisation methods (MR, x-rays, ultrasound, PET etc.) based on nanotechnology may yield earlier detection of illness, more precise identification of injuries and enhanced control and management of surgical interventions. Drug delivery with the aid of nanocapsules may enable more flexible dosages and increased organ specificity, i.e., guidance of the drug to the right spot in the body. Nanosensors can register health status by measuring chemical substances in the blood. The signals can trigger drug delivery or report status to the hospital or the treating physician. New drugs will consist of customised molecules that interact optimally with the biochemical surfaces of the cells in specific organs. N&N will contribute to the development of new, biocompatible materials for implants and artificial organs and functions, e.g. artificial retinas.

N&N can also contribute to solutions for challenges in **Ocean and Food**. Reduced fouling of surfaces can be achieved by controlling the nanostructure. Control of the material structure at the nanoscale will lead to lighter and stronger structural materials. Protein programming of the properties of different fish species may be a future technology for the development of a more efficient aquaculture.

Microsystems and nanosensors can be used to trace the origin of products, to monitor food condition and even to notify the optimum time for slaughter. Feed production from natural gas by means of synthesis of proteins can be optimised with the aid of new catalysts. Use of nanostructured and functionalised materials in foodstuffs packaging will improve the products' quality and shelf-life.

Even the nanotechnological components of a product will as a rule be invisible to the consumer. That is why a conscious **dialogue with the population** about the opportunities and risks following in the wake of nanotechnology is so important. It is of fundamental importance for Norway as a nation to have sufficient expertise in mathematics, natural science and technology -- and thereby N&N – so as to meet and absorb an unknown future.

Progress in N&N is happening rapidly and Norway must be an active participant if we are not to lose ground in a steadily tougher international R&D climate. Failure to invest will mean reduced expertise in fields that appear absolutely central to future industrial development, welfare and standard of living. **The question is not whether Norway should invest in N&N, but to what degree and in which areas**. This report endeavours to provide clear recommendations about this.



New priorities in Norwegian research policy.. Source: Report no. 20 to the Storting (2004-2005), White Paper Commitment to Research.

What is happening in Norway?

- *The Norwegian investment in the field of N&N is, as of 2006, modest, also in relation to the population.*

- *Relevant programmes on which N&N can hitch a ride have been created: microtechnology, new (functional) materials, functional genomics. Relevant scientific evaluations have been made by disciplines and by leading groups in connection with centre applications (SFF, SFI and COE).*

- *The research institutions have created strategic plans for N&N. Several have invested in heavy infrastructure and there exist national and international cooperation networks.*

- *N&N in the research and education sector is happening today first and foremost in the Oslo area (the University of Oslo (UiO), SINTEF, the Norwegian Defence Research Institute (FFI) and the Institute for Energy Technology (IFE) and in Trondheim (the Norwegian University of Science and Technology (NTNU) and SINTEF), partly also in Bergen (the University of Bergen (UiB). Smaller, but relevant activities are to be found elsewhere, primarily related to the university and college sector.*

- *Established industry is showing increasing interest. Both established industrial companies and SMBs (small and medium businesses) have nano-related activities and products. New materials and concepts with commercial potential are being identified in the scientific research communities.*

The Research Council of Norway and other support schemes

In 2002 the Research Council of Norway started the programme "Nanotechnology and New Materials" (NANOMAT, www.forskningsradet.no/nanomat) as a consequence of the FUNMAT initiative. In all, the programme channelled about NOK 290 million to projects in the first four-year period, the budget for 2006 is NOK 76 million. Around 30% of NANOMAT projects may be said to fall under N&N. The NANOMAT programme has so far focused on new materials, particularly functional materials. It is, however, difficult to state the N&N proportion exactly, since this overlaps so much on the materials field.

N&N, as it is defined in this report, has a very wide sweep. This means that the Research Council of Norway is also funding relevant research through **other instrumentalities**. The most important programmes and schemes are Clean Energy Systems of the Future (RENERGI), Free-standing projects, Storforsk, Young Outstanding Researchers (YFF), Eco-friendly Gas Power Technology (CLIMIT), User-Managed Innovation Arena (BIA), ESRF follow-up research, strategic university and institute programmes (SIP/SUP) and SkatteFunn. In 2005 total investment in new materials and nanotechnology via the Research Council of Norway totalled approximately NOK 140 million.

In addition, N&N research is funded through Nordic research programmes and EU based.

The research and educational institutions

In February 2001 the partners in the **FUNMAT** consortium, i.e., the Institute for Energy Technology (IFE), the Norwegian University of Science and Technology (NTNU), SINTEF and the University of Oslo (UiO), submitted an initiative to the Government regarding a coordinated, integrated national programme in functional materials and nanotechnology, focusing on energy, eco-friendly process technology, microsystems and biocompatible materials.

The Norwegian N&N programme is to a large extent taking place at these institutions, but has a scientific range that exceeds the materials initiative focused on. Examples of other topics are soft and complex materials, polymers, drug delivery systems, theoretical chemistry, molecular biology and molecular medicine. These institutions receive around 80% of the total appropriations in NANOMAT, of which 49% lie within the FUNMAT area. NANOMAT has until 2006 allocated NOK 329 million to projects for the period 2002–2009.

The University of Bergen currently has individual activities in N&N, but wants to establish broader activities related to nanobio, NanoBasic, nanoprocess and nanoethics. Vestfold University College (HVE) is part of a close industrial collaboration on the basis of microtechnology. The Norwegian Defence Research Institute has advisory functions and research activities in the area. A more detailed overview of the Norwegian the activities may be found in appendix 1.

The research institutions have had a central place in **national initiatives** related to microtechnology, functional materials and functional genomics. This has resulted in the development of infrastructure and expertise in these fields over the last few years. Even if the development is not actually in N&N, these programmes will give Norway an essential basis for being able to develop N&N in directions that depend on new materials, are oriented towards ICT and microsystems or are biological/medically oriented.

The research institutions have themselves made considerable **prioritisations** in their internal strategies and grants (see Appendix 1), which clearly shows that they consider that N&N will become very important to future expertise development and technology, and thereby to future industry.

The two biggest programmes in N&N infrastructure in Norway are MiNaLab/SMN in Oslo, which opened in 2004, and NTNU NanoLab in Trondheim, which is under construction. Operations at MiNaLab/SMN embrace functional materials, micro and nanotechnology. SINTEF's activity has its main focus on industrial applications. NTNU NanoLab is being established with nanotechnological infrastructure for synthesis and definition of nanostructures by chemical, physical and biological methods plus characterisation of nanostructures. The laboratories at HVE are being established in order to build microsystems. The Jeep II reactor at IFE constitutes important infrastructure for Norwegian materials research, partly also for N&N.

In the last few years, many new inter-institutional **collaboration constellations** have been developed with sometimes considerable elements of N&N. They are coming in response to the invitations to big applications: the Centres for Outstanding Research (SFF), the Centre for Research-Based Innovation (SFI) and Storforsk, establishment of strong business clusters in the Centres of Expertise (CoE) and strategic measures such as the Gemini Centres between SINTEF and NTNU/UiO.

The application round for **SFF** showed that several strong communities have gathered around relevant topics: Smart materials for future device technology (NTNU); Centre for Solid State and Nano-ionics (UiO); National Centre for Complex Matter Science (UiO); Centre for Catalytic Materials and Surface Dependent Phenomena (UiO); Centre for Energy and Environmental Catalysis (NTNU); Trondheim Centre for CO_2 Capture – Enabling Research and Technology (NTNU); Centre for Theoretical and Computational Chemistry (UiTø) and the Centre for multiscale molecular modelling with applications to novel structures of superior functionality (UiB). In addition, applications were received from biological and medical communities with relevance to bioN&N.

The same applied to the SFI applications, of which several focused to a lesser or greater extent on N&N: Innovative Natural Gas Processes and Products (UiO); Sustainable Hydrogen Energy Technology (IFE); Centre for Micro and Nanosystems (SINTEF); Centre for Innovative Molecular Diagnosis and Therapy (UiO) and the Wind Technology Research Centre (SINTEF Energiforskning).

Business and industry

The Norwegian economy is characterised by raw material, energy and goods production. To a greater extent than many comparable industrial nations, Norway lacks a R&D-based industrial sector with a focus on research-heavy, futuristic products such as pharmaceuticals, biotechnology, computer technology and functional materials. There are few Norwegian industrial locomotives with a strong self-development of new technology for an expansive global marked. The situation is reflected in the level of Norwegian research both in relation to the OECD and in comparisons between different industrial segments.

Norwegian industrial companies currently have expertise and R&D activity in the field of N&N inter alia in the following areas:

- *Nanostructured materials and nanoparticles (Swix, Madshus, Conpart, Keranor, Prototech, Nor-X Industries, Abalonyx, ScanWafer/REC, Borregaard, Borealis, Elopak, Jotun)*
- *microsilica, where the properties are governed from the nanoscale (Elkem)*
- *nanotubes and nanocones of carbon (n-TEC, Carbon Cones, Elkem, Carbontech Holding)*
- *catalysis (Statoil, Hydro, Yara)*
- *special components in ICT and optics (Ignis Technologies, Norspace, Infeon Technologies/Sensonor, NERA)*

- *biomagnetic separation of cells (Dynal Biotech Invitrogen)*

- *products for medical imaging diagnostics (GE Healthcare)*

- *"slow release" of medicines (Nycomed)*

- *medical diagnostics (NorChip)*

The Research Council of Norway has a set of instrumentalities oriented towards the needs of industry (SkatteFunn, BIA, BIP, KMB, FORNY). In the last two years NANOMAT has advertised user-managed innovation projects (BIP), for which only industry could apply. In the 2006 call-for-proposals round, the number of applications was tripled, at the same time as the funds applied for were increased sevenfold. This indicates an **increasing interest** in nanotechnology and new materials on the part of Norwegian industry. The majority of the applications in 2006 was within nanostructured materials and surfaces, and the applicants included companies of all sizes. An interview round of relevant companies in 2005 showed that Norwegian companies were positive to nanotechnology, but are taking a wait-and-see line [Sintef 2004]. It is therefore important that N&N programmes at the R&D institutions be broad, robust and of a high quality so as to stimulate industry to a greater commitment to N&N.

During a seminar in the spring of 2006 with a focus on materials technology for the oil industry, led by PETROMAKS, it was pointed out that nanotechnology can contribute to solving many of the oil industry's problems, particularly in connection with materials and sensors. RENERGI already has projects on materials technology that can trigger new energy technology, and CLIMIT has similar for CO_2 sequestration.

International contacts

The EU

In three calls for proposals for the EU's sixth framework programme in the field "Nanoscience, nanotechnology, materials and new production technologies (NMP)" from 2003 to 2005, success for Norwegian applicants was on the increase. Forty-five Norwegian partners from universities, colleges, research institutions and industry are participating in 33 projects in the NMP field. In addition, there are 77 Norwegian participations in a total of 34 hydrogen-related projects under the thematic priority area "sustainable energy". Norway has the coordination responsibility for ten projects; five in NMP and five in sustainable energy. The nanotechnology element is important to several of the projects. The groups enjoying great success in the EU's sixth framework programme typically achieve funding through NANOMAT as well. Work is therefore currently in progress to position Norwegian R&D communities and industry vis-à-vis the EU's sixth framework programme. The Research Council of Norway is participating together with other countries' and regions' research councils in MATERA, an EU collaboration for project funding in materials and nanotechnology.

Norwegian communities with relevance to N&N enjoy very extensive research collaboration with European research institutions in chemistry, physics, materials science, biology, medicine, microtechnology and nanotechnology.

The Nordic area

NorForsk and Nordic Energy Research fund researcher exchange, networks, researcher schools and research projects in materials technology with N&N elements. The Nordic Innovation Centre funds, under the Nordic micro and nanotechnology initiative MINT, Nordic nanotechnology projects, in which Norwegian players led by SINTEF are numerous. The objective is to find practical, commercial applications of nanotechnology.

Bilaterally

Norwegian R&D communities enjoy, in the same way as vis-à-vis the EU, a close professional collaboration with cutting-edge scientific communities in the USA and Japan. In the long term we expect an increase in the bilateral collaboration with the USA and Japan, largely on the basis of the technology treaties with these countries. On the institutional level there are agreements on cooperation in materials and nanotechnology with leading milieus in the USA and Japan. Because of their scientific quality in functional materials and nanotechnology, certain Norwegian communities have been invited to join projects funded by the Department of Energy in the USA and the New Energy and Industrial Technology Development Organization (NEDO) in Japan. Collaboration with Canada and China in the field of N&N is expected to increase in consequence of bilateral support schemes. Through NANOMAT, the Research Council of Norway funds projects with integrated international cooperation.

International research collaboration takes many different forms and is often individual-based. A substantial proportion of such cooperation is not very much related to formal agreement systems and is initiated and pursued via personal contacts between researchers.

International laboratories – infrastructure
Certain types of laboratory and instrumentation are so resource-intensive that it is not very practical for them to be created and operated by individual countries. Access to heavy infrastructure will be a precondition for research in the field of N&N on the highest level, and demand for such equipment is a sign of quality. This is particularly important for small countries. Norway is a member and thereby enjoys access to important facilities such as the European Molecular Biology Laboratories (EMBL), CERN and ESRF, and in general to European laboratories classified as “Large Scale Facilities”. In the EU’s seventth framework programme, it will be possible for Norwegian milieus in the field of N&N to apply, together with the host institution, to use other special infrastructure in Europe.

Through membership in the European Synchrotron Radiation Facility (ESRF) and the Swiss-Norwegian Beam Lines (SNBL) at the ESRF, Norwegian researchers enjoy especially good access to synchrotron radiation at the Grenoble facility. Access and follow-up research are funded in part through the Research Council of Norway, in part by the Ministry of Education and Research. Other relevant facilities are BESSY, ISIS, Daresbury, Hasylab, MAXlab and ILL.

N&N in society

- *The future will be shaped by information technology, biotechnology, materials technology and nanotechnology, plus the interplay and convergence between these technologies.*

- *N&N opens the door to progress and new possibilities in areas such as safety, health and the environment, and can thereby contribute to meeting important societal and industrial needs.*

- *Only to a small extent have we mapped and understood how N&N in the broadest sense is capable of affecting human beings, society and ecosystems. Systematic risk assessments are therefore essential.*

- *N&N has the potential for radical breakthroughs and can stimulate epoch-making research in interplay with other technologies. Ethical issues must therefore be considered carefully.*

- *Legislation and regulations must be adapted to N&N.*

Social and economic significance

The leading industrial countries consider that mastery of nanotechnology is crucial to their economic and technological **competitiveness** in the 21st century [National Science 2001; the Danish Ministry of Science 2004]. Most of today’s new nano-products are in the realms of microtechnology and advanced materials technology with applications in sport, cosmetics, surface treatment and textiles. Well-established international players are under way, and there is an undergrowth of SMBs developing innovative products. In the future we may expect applications in most societal areas.

Internationally, there is large-scale investment in new technology to create new nanomaterials and develop new areas of use. In the USA about 20,000 people are now working on nanotechnology. [National Nanotechnology 2006]

N&N can contribute to increasing the gulf between poor and rich countries because of the high demands on expertise level and big R&D costs [ETC Group 2005]. On the other hand, many people think that the **nano gap** can be avoided and that N&N can be an important tool for products and technology that promote global development and equalisation.

Examples of applications that are important to development in the third world are:

1 Energy storage, production and use
2 Enhanced productivity in agriculture
3 Filters and catalysts for water purification
4 Diagnosis of diseases
5 Vaccines with controlled drug delivery

6 Treatment and storage of food
7 Air pollution and purification
8 Structures and buildings
9 Follow-up of health status
10 Detection and control of pests
[Singer 2005]

Health, the environment, risks and safety

In parallel with the many opportunities that follow in the wake of N&N, there is also uncertainty about possible health and environmental threats [the Research Council of Norway 2005(f)]. Certain new applications consequent on progress in N&N rely on the fact that the properties of materials change radically when the size of the systems is reduced. New types of nanoparticle can be spread in the environment. How such particles will affect human beings and ecosystems is not very well understood. It may be argued that **the precautionary principle** should be deployed, but at the same time over-restrictive principles must not stop the development of new products and applications/methods. On the other hand it is essential that systematic risk assessments be conducted and documented so as in the best possible way to ensure knowledge and control of possible health and environmental hazards.

Possible harmful effects of nanostructured and hybrid materials, including their **toxicology** (toxicity for human beings and other organisms) and eco-toxicology (damage due to accumulation in ecosystems) [Malsch 2005] must be correlated with knowledge of naturally occurring nanoparticles, to which human beings have been exposed throughout their evolution [Royal Soc. 2004, page 36].

In biological and medical applications a number of ethical and safety questions will arise when bioN&N can lead to highly effective diagnostic aids, new drug delivery techniques and new methods of cultivating stem cells and tissue.

Internationally, progress in the field of N&N will be used for **military** purposes. Many military applications can also be misused for terrorism or lead to a lower threshold of violence and attack. It is therefore important to be aware of the extended possibilities to which N&N can contribute [Altmann 2005].

Since nanotechnology is based on established disciplines and has a central place in national thematic and technological prioritisations, the above-mentioned issues are just as central to these disciplines and societal technologies as to nanotechnology in itself. Research and expertise development must thus be seen in an **integrated perspective**, so that N&N becomes a common good with minimal negative ripple effects.

Ethics and society

The new and positive opportunities that N&N offers for social development and prosperity, and a possible undesirable use of N&N, both raise ethical questions. This also includes the recognition that it will not be possible to detect all the problematical aspects of a technology development by means of public regulations.

In connection with biotechnological applications of N&N, important questions can be raised related to **normality** and health (how non-conformity is to be tolerated), **privacy** protection (how sensitive information is to be protected) and **indirect consequences** (what health effects are transmitted indirectly, via society and culture). Important innovations may be too expensive for others than a tiny elite to benefit from them.

New medical diagnostics may led to an increased distance between what can be diagnosed on the one hand and what can be treated, what we would like to treat or what we can afford to treat on the other. These challenges need to be illuminated.

N&N can create the basis for a **sustainable** development, and can contribute to the reduction between the rich and poor in the world. It is not, however, obvious that such considerations enjoy a central place in research-policy prioritisations. When ethical evaluations are integrated into research, the likelihood of achieving a desired development in specific fields is increased.

Legal challenges

The number of **patents** including the word “nano” in the title is growing rapidly, and in the period January 2000 to April 2005 more than 15,000 patents were registered worldwide [NanoVantage 2005]. This is the first new area in a long time in which fundamental ideas are being patented right from the start. Patents often endeavour to be broad and generic, and rights may thereby benefit industry also in areas outside the original core area. In recent years the Norwegian universities have become much more active in patenting, and this will affect the implementation of innovations in N&N. IP rights are often a precondition for our succeeding in commercialisation of R&D results. International trends in patent legislation related to N&N must therefore be carefully followed by Norwegian players too.

Another point that requires for legal clarification is the **law of liability**. Present-day legislation does not appear to be adapted to the new opportunities of nanotechnology [Davies 2006]. In this area, work is in progress on creating international guidelines [Malsch 2005].

Norwegian legislation and guidelines for addressing ethical, societal and environmental aspects of the use of N&N do not yet exist. It is important to get laws and regulations in place both nationally and internationally. It is equally necessary to lay down international technical **standards**. There are many initiatives for doing this at national level, but so far this has not converged internationally [Malsch 2005].

The need for new **regulation** in relation to N&N should be charted rapidly. A framework for regulating N&N should both promote initiative and innovation and clarify key factors related to society and the environment. Such a framework will reduce the chances of undesirable reactions among the consumers and decision-makers.

Discussion of organisational measures

In this chapter, certain objectives and needs are discussed and analysed, which are to be attained through scientific activities, thereafter various models for the organisation of N&N programmes. This forms the background for the choices to be made in the next chapter, in which the actual strategy is presented.

Needs-driven or knowledge-driven?

- *Needs-driven: Research motivated by probable applications and research-strategy prioritisations (Market pull).*

- *Knowledge-driven: Curiosity-driven research initiated by research communities, with or without focus on potential applications (Technology push).*

- *Integrated: An optimal combination of needs-driven and knowledge-driven motivations. Such a mixed strategy can yield synergy effects between basic research and industry-oriented research. Because of the time-scales that apply to discipline and technology development in the field of N&N, this may mean faster implementation in industry and commercial products.*

A paramount objective is for N&N to contribute to development of natural-science disciplines, technologies and industry. New ideas, materials and components can thereafter be integrated into industrial development related to suppliers of products and technology/expertise to enterprises, particularly in nationally prioritised thematic priority areas. Internationally, it is emphasised that strong basic research in the field of N&N and into interfaces with other technologies will constitute the basis for a broad exploitation of N&N in industry and the public administration. It is an objective to facilitate innovative basic research so as to encourage a broad and competitive register of commercialisable ideas.

Needs-driven motivation

Research motivated by applications in society or from a paramount research policy standpoint (e.g. through the White Paper on Research), may be said to have its origin in market needs (thus “market-pull”). This is often research on a short time-scale, motivated by and intended to lead to **applications**. When industrial products and applications are the main objective, it is natural that relevant companies participate in research and identify prioritised research challenges (user-managed projects). Such participation will occur either through the companies’ own research, through collaboration with research institutions or through (partial) funding of fellowships and projects in the university and college or the institute sector. The White Paper on Research promises a major increase in appropriations for such research. We may expect further incentives in the future. It is important to stimulate existing industry to integrate N&N into its own R&D so as to strengthen competitiveness and development of (new) products. At the same time, given the orientation of Norwegian industry, we will require special measures to stimulate to new industry and increased wealth creation in new areas. This will demand instrumentalities such as user-managed innovation projects, as well as pure innovation incentives, for example through the FORNY scheme and Innovation Norway.

Research policy considerations may also underlie needs-driven research. These may dictate that Norway should invest in a given area, on the basis of a pure industry perspective and/or a broader social perspective, for example energy, health or the environment. The motivation may also be a need to create new industrial fields. If there is little or no industry in the area, the objectives must be followed up with strategic public programmes (although focusing on quality).

An international example of needs-driven N&N is the electronics industry, in which development in nanoelectronics is driven by the big microprosessor suppliers.

Knowledge-driven motivation

Research that is motivated by scientifically interesting questions and that emerges from research communities, is here termed knowledge-driven (or “technology-push”). These are often activities in which knowledge development takes place over a longer time-frame, where applications are not necessarily clearly defined, or where research aims at a broad **expertise basis** with many applications in view. Such research (free or strategic) derives its funding mainly from public sources: Basic appropriations, free projects, programmes, strategic programmes, also expertise projects with user participation (KMB). For parts of N&N the division between basic research and applied/industrial research will be washed out, because of a short time between discovery, patent and application. At the same time the new Universities Act, which gives the universities property rights in the exploitation of new knowledge, increases the attention given to commercialisation of the results of basic research.

Carbon nanotubes are an example of a product with great application potential that has emerged from knowledge-driven motivation. Here the discovery of the material and its unique properties came first; since then, industry and research institutions have demonstrated a broad spectrum of application possibilities. Due to the usefulness of nanotubes in many technological areas, industrial production of nanotubes is expected to rise from 55 tonnes in 2005 to over 1,600 tonnes by 2010 [Cientifica 2005].

Integrated motivation

A good Norwegian strategy for N&N is considered to be one that contains elements **motivated by both market and knowledge needs**, that is, the total national needs. The objective of such an integrated motivation is to build new knowledge in selected segments of N&N, to develop expertise in generic application opportunities and facilitate innovation and industrial development. It will also make it easier to build bridges between the short time perspective of owner interests in industry and the long-term thinking that is required if we are to succeed with N&N. We should endeavour to create research communities that achieve synergies between these time-scales and between different players.

If Norway is to develop competitive N&N for an international market, there must be no renunciation of scientific quality and innovation within the selected areas. At the same time this demands that the key research communities have the will, ability and capacity to perform both forms of research, that synergies are developed and that the division of labour and integration of activities at various research institutions is successful. This makes clear demands on the implementation plan for N&N. Special measures are proposed in this strategy so as to address this.

Coordination

- *N&N demands robust, high-quality research communities, which possess adequate resources while at the same time working on relatively broad objectives and on specialised, state-of-the-art research. This requires good scientific management.*

- *Investment in N&N will yield big gains and synergies through coordination with other associated national programmes, for example in energy technology, petroleum, ICT/microsystems, functional materials and biotechnology/gene technology.*

- *National coordination and dedicated resources may yield optimal construction, operation, accessibility and exploitation of infrastructure and tools for N&N and thereby contribute to N&N being utilised in new areas and by industry.*

- *The research system can stimulate activity in new innovative topics, collaboration with top international communities and professional renewal, inter alia via support for young researchers.*

Critical mass – strong research communities

A consistent problem with Norwegian research is small researcher groups, critical dependence on key individuals and lack of resources to operate and exploit advanced scientific equipment. Such fragmentation is particularly unfortunate for N&N, which is characterised by a high degree of interdisciplinarity and by advanced laboratories. Without a wholly satisfactory solution for this, Norway cannot play the desired role in N&N, nor expect any large-scale innovation and new wealth creation on the basis of N&N and its interplay with disciplines and thematic priority areas.

In order to develop N&N in a robust, long-term perspective, it is essential to create mechanisms that provide selected (evaluated, highly-competent) researchers and groups with internationally **competitive conditions**. We must demonstrate confidence that the ablest groups in Norway, also in the future, will deliver quality and quantity. This opens the door to the establishment of major projects, or else centres (confer SFF, SFI, COE and Swedish consortia). The proposed programme should be permeated by focusing on certain niches and on communities with special experimental resources and/or particularly great expertise. This can contribute to Norwegian N&N in niches rapidly achieving international weight and quality. The investment should take place on the basis of competition and with international evaluation, in order to achieve the most precise possible targeting.

In order to work with complex problems of an interdisciplinary character, in which theory and experiment must in part be integrated, we need highly competent milieus of a size that makes for an efficient work situation and at the same time allows room for creativity. One consequence of this is good exploitation of research funds (value for money). By strengthening existing groups (if necessary founding new ones), we should be able to create **robust milieus and projects** that at one and the same time are conducting basic research, following up new ideas towards commercialisation and having the capacity for collaboration with industry. An integrated motivation is also important on this level. A precondition is long-term funding. The milieus selected (through competition) are expected to play an active role in N&N education and researcher training; students will thereby be exposed to basic research and industry-oriented research. Such activities should be evaluated regularly. In order to create dynamism in the system, funds should be managed in accordance with this kind of evaluation.

It is necessary that such a public investment in robust communities be followed up by the institutions with permanent posts and infrastructure measures. At the same time, the establishment of robust communities must not displace curiosity-driven research within smaller groups that scientifically and innovation-wise are competitive within their niches. This will have to be subject to budgetary reconciliation.

Research management

Big N&N research projects oriented towards knowledge development, methods or thematic foci, will typically have a high degree of interdisciplinarity. They will also integrate theory and experiment, require operational infrastructure, cooperation with industry or follow-up of new ideas with a view to commercialisation. **Research management is required for a successful investment**. This may include stronger target management, particularly for more applied and industry-oriented projects, incentive schemes and use of portfolio tools. Good models for this must be expected in big N&N projects. At the same time, there will be a need for increased national coordination of projects in order to exploit complementary knowledge and methods. The same applies to heavy infrastructure, see next section. In this way the Research Council of Norway has positive experience with the FUNMAT consortium, which coordinates several big projects funded through NANOMAT. A similar consortium may play a role in the implementation of a N&N programme, particularly if the number of partners (or associated partners) and the scope are extended somewhat.

National coordination of infrastructure

N&N is dependent upon dedicated methods; of synthesis and fabrication, characterisation, theory and modelling. Resource considerations immediately dictate a limited number of heavy N&N laboratories in Norway, which was also recommended in the Foresight project “Materials 2020” [the Research Council of Norway 2005]. Much of the experimental equipment and infrastructure (particularly advanced clean rooms) is extremely expensive, both in procurement and operation. Not least is there a need for highly-qualified technical personnel. A high degree of exploitation of the laboratories should be sought. Since such equipment is too expensive and complex to be installed at all institutions, it will be highly beneficial for nano-research overall to make certain well-equipped laboratories **available to** all interested players in Norway, whether from the research and educational institutions, the institute sector or industry.

If we are to be able to develop new and cost-effective technology within the thematic priority areas, it is important to combine nanotechnology with other advanced technology. For a small country like Norway, this can be done most efficiently via good collaboration models.

A common infrastructure makes a lot of demands: Modern instrumentation with sufficient capacity; technical assistance and good operational forms that ensure availability; methodological expertise that exploits the potential of the instrumentation to the utmost; funding schemes that ensure reasonable access for external and which for industry’s part are in conformity with international competition regulation.

The financing of a national infrastructure is a joint task for the institutions, the Research Council of Norway and the authorities. National infrastructure, in a virtual network, must be subject to paramount control. Proposals are discussed in greater detail in the chapter “Instrumentalities” on page 32.

Funding models

- *Integrated model: N&N is realised through current funding schemes and instrumentalities (including strategic programmes).*

- *Dedicated model: All N&N is gathered together in a single dedicated programme.*

- *Focused model: A mixture of the two above; N&N is strengthened through instrumentalities for national prioritisations in the Research Council of Norway, at the same time as a focused programme has the responsibility for N&N.*

In the preceding sections it was argued that Norwegian investment in N&N should be the consequence of an integrated motivation; partly needs-driven, partly knowledge-driven. The programme requires robust communities and projects of a high quality, good research management and advanced infrastructure. In addition, it is required that we deal with **several time-scales**, often all at once. N&N is an integrated part of the MNT subjects, but nonetheless a separate, new field with potential for development of entirely new knowledge, partly of an **interdisciplinary** character. N&N must be developed into a key tool for innovation and new industry. A programme must be robust and satisfy several different kinds of development.

If Norwegian scientific communities are to be at the cutting edge of research within niches of N&N, we need determined investment with this in mind. Not until then will the milieus become real resources for industry in highly competitive areas and be able to generate new commercialisable ideas at the leading edge of technological development. The existing instrumentalities in the Research Council of Norway for nationally prioritised thematic and technological areas have other main missions than to develop generic knowledge in N&N. An **integrated** model may thus be not wholly suited to facilitating an optimal development of N&N in Norway.

The opposite extreme is to envisage the gathering of all N&N in a single **dedicated**, independent programme. This may be well-suited to constructing various expertise platforms, but it may also hamper the cooperation between different instrumentalities and players that most effectively support the nationally prioritised areas.

It therefore seems most expedient for N&N to be financed in such a way that both the above-mentioned main considerations are satisfied. In such a **focused model**, N&N for national focus areas shall be funded through existing instrumentalities of the Research Council of Norway, while the long-term, fundamental and expertise-developing responsibility is vested in a separate programme. This requires that essential new resources be made available.

Education, recruitment and communication

- *Education, researcher training and recruitment are crucial factors in being able to scale up N&N operations at the desired tempo. In addition to the actual N&N field, this applies to associated basic subjects.*

- *New educational facilities of various types are now being introduced for N&N at several universities. This offers opportunities for broad collaboration with regard to courses at Ph.D. level and in researcher schools.*

- *Broad and high-quality research is a precondition for a good and interdisciplinary N&N education.*

- *Dissemination of results from N&N is a vital task and can contribute to increased interest in natural-science and technological education.*

Education in N&N

International trends show two approaches to education; a discipline-based and a multidisciplinary. The former integrates N&N into already existing, discipline-oriented educational tracks. The latter offers explicit educational programmes in N&N. **Discipline-based** N&N educational courses are based on a discipline (mesoscopic physics within solid-state physics, nanochemistry within physical/inorganic/organic chemistry etc.) and meet needs for focused cutting-edge expertise. Examples may be nanoscale physics of materials; nanotechnology related to miniaturisation within microtechnology; photonics related to development within micro and communication technology, the axis from functional materials to nanostructured functional materials. In biological education there are bioengineering and biophysics programmes that raise nanotechnological issues. The discipline-based nanotechnology courses of education are particularly relevant at the master's and doctoral levels.

The **multidisciplinary** approach to N&N education starts to a greater degree at bachelor's level. In the first semesters a common scientific basis is provided by chemistry, physics, biology and electronics, dedicated subjects in nanotechnology plus mathematical subjects and IT. This common basis enables subsequent specialisation. Typically, there are a limited number of profile areas (areas of study) that may be chosen, but at the same time a sufficient freedom of choice between topics. Examples of profile areas are: nanostructured materials; nanotechnology for biology/medicine, energy and the environment (catalysis, separation, energy harvesting); the MEMS/NEMS axis etc.

In recent years, Europe has seen the introduction of multidisciplinary nanotechnology courses of education at master's level in collaboration between **several institutions**. These are characterised by the multidisciplinary nature and the academic depth being strengthened through cooperation between complementary discipline-based study programmes at various institutions.

The NTNU has recently established a multidisciplinary study programme in nanotechnology as a five-year master's programme, as part of its chartered-engineer course. The first admission of students was the autumn of 2006. A five-year master's programme is in the process of establishment at the UiB with a planned start-up in the autumn semester of 2007. The UiO is currently creating a discipline-based curse of study master's and Ph.D. levels related to the programme "Materials and Energy for the Future" (MEF).

The traditional **basic disciplines** tend to have complementary approaches to a number of questions that are found in a pure form in N&N. In many cases, therefore, they will drive the discipline development in ways that benefit N&N. It is important that N&N education become a good supplement to the traditional disciplines.

Communication

Only to a limited degree will the ordinary citizen and the decision-maker be informed about the opportunities and challenges related to natural science and technology in general and N&N in particular. The communication aspect is particularly important to N&N, which to a large extent operates on the basis of products and components that cannot be seen with the naked eye. At the same time, N&N will have great significance for social development, health and welfare, and the consequences for the individual may be extensive. Dissemination and dialogue are important, both to give the population a **realistic picture** of possible future consequences of N&N, and to get essential feedback from the general public. Relevant instrumentalities are:

- Layman conferences
- Radio, TV, newspapers
- Research festivals
- Dissemination courses for journalists
- Lectures for companies, associations etc.
- Meeting-places for industry and R&D milieus
- Conferences with leading international researchers

Such a communication strategy should be coordinated by the Research Council of Norway, confer the chapter "Instrumentalities" on page 32.

Research strategy for N&N

The chapter suggests content and size for a forward-looking Norwegian investment in N&N. It opens with what Norway should prioritise; thereafter follows a discussion (on pages 32-40) of how the programme should be implemented; and finally, a size for the programme is recommended. Pages 43-46 summarise advice to different players in the field. Important prioritisations are submitted on pages 32-40, plus recommendations for instrumentalities in order to achieve an effective organisation and implementation. This is more of a strategy than an operational plan, with a focus on overarching questions and instrumentalities. This means that the institutions are relatively invisible. A number of institutions have drawn up clear strategies for N&N, which are valuable in this work.

Prioritised focus areas

The N&N strategy shall support national thematic and technological prioritisations, and designate four thematic priority areas:
1. Energy and the environment
2. ICT and microsystems
3. Health and biotechnology
4. Ocean and food.

Certain scientific areas constitute an open and common basis for N&N. The strategy designates the following expertise areas:
- *Materials*
- *Interface-/surface science and catalysis*
- *Fundamental physical and chemical phenomena and processes at the nanometre scale*
- *BioN&N*
- *Components, systems and complex processes on the basis of N&N*
- *Ethical, legal and societal aspects.*

A key basis for the areas above is being able to create nanomaterials and nanosystems, to characterise and understand their properties. For this we need advanced and expensive infrastructure and tool platforms:
- *Synthesis, manipulation and fabrication; characterisation; theory and modelling.*

A national strategy for N&N requires a good **balance** between breadth and focus, and between basic research and application-oriented R&D. At the same time, the strategy ought to deal with both the short and the long time perspective. Prioritisation is essential in order to achieve sufficient focus, tempo and competitiveness within areas designated in the strategy. At the same time, the door should be held open for curiosity-driven research that will stimulate to new knowledge.

Society and industry are demanding research with a relatively short time horizon that yields identifiable utility effects. These wishes must be balanced against curiosity-driven basic research on a longer time-frame. For future wealth creation it is particularly important to stimulate to new knowledge and technology that not until the long term provides new products and new industry. The research and educational system must, therefore, satisfy and balance the needs of society and industry, in both the short and long terms. Experience shows that big discoveries and technological leaps generally emerge from curiosity-driven research. That is, gains cannot be made by merely considering imminent needs. On the other hand, needs-driven research can also create considerable new knowledge and fundamental research.

The proposed strategy endeavours to balance breadth and focus. By designating the **four thematic priority areas** Energy and the environment, Health and biotechnology, ICT and microsystems plus Ocean and food, the foundations are laid for strengthening the thematic priority areas and technology areas that were prioritised in the Research White Paper. N&N research in these areas is primarily needs-driven, and may be followed up through a number of programmes and instrumentalities of the Research Council of Norway. Radical progress in the field of N&N may lead to rapid progress in several of these areas, in terms of both technology and wealth creation. Below follow tentative recommendations in each of the thematic priority areas. An essential focusing must be done in consultation with the Boards and the expert panels that the Research Council of Norway has established for the areas. This will ensure that national advantages are exploited and that N&N is part of an integrated with market, quality and expertise as its keywords.

If N&N is to stimulate technological development within the thematic priority areas, a high degree of expertise in the core of N&N is required. It is therefore recommended that we establish a collection of **tool platforms** and **generic expertise areas**. These are relevant to all the thematic priority areas and all N&N, and at the same time create a strong and necessary basis for long-term basic research, expertise and methodological development. One example is new materials, which has a central place in all of the N&N areas.

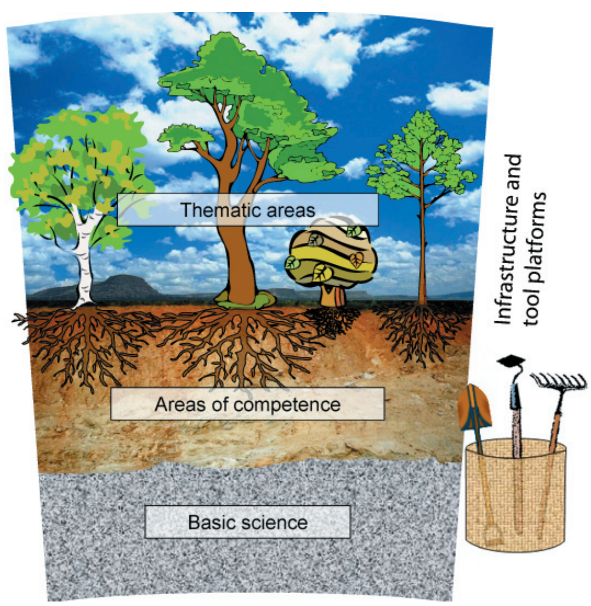
N&N demands advanced methods of synthesis and fabrication, characterisation and manipulation plus theory and modelling, that is, heavy and integrated **infrastructure**. This will also benefit N&N in the thematic priority areas, which will also drive methodological development. The N&N strategy makes proposals for long-term funding and coordination of such infrastructure.

Experimental activity in order to demonstrate the new technology makes demands on laboratories that exceed what is offered by facilities for fundamental research. The technology component of N&N, that is, the R&D arena in which the research institutes, universities and industry collaborate in laying the groundwork for new wealth creation, have special infrastructure needs which must be taken into account in the implementation of the programme.

Thematic priority areas

N&N oriented towards the four thematic priority areas will first and foremost be technology and application oriented, on the basis of science. In many contexts science and technology will here merge into one another. They are closely linked and may be said to fertilise one another. The nationally prioritised areas in the Research White Paper are already partially covered through a number of funding schemes in the Research Council of Norway. This makes it possible to have a specific N&N focus within these areas and thereby contribute to renewal and development. In order to achieve this, new N&N instrumentalities must be incorporated into these funding schemes.

The strategy envisages scientific **coordination** and broad projects in the field of N&N in order to bind together activities that are thematic and technologically oriented with long-term development of expertise. For this we need a separate set of customised instrumentalities (see page 32).



The suggested areas of competence are generic, and are necessary for all thematic areas. In addition they will contribute to new understanding and insight. Conversely, research within thematic areas may lead to new generic insight with a variety of applications. Knowledge will thus move both up and down in the figure. Access to advanced infrastructure and tools is decisive for all parts of a national effort.

N&N in the thematically-motivated questions will have a much stronger character of **basic research** than what is naturally regarded as the responsibility of the existing programmes and instrumentalities. It may also be appropriate to initiate new activity that does not yet have a basis in any Norwegian milieus. Such choices may be assisted through paramount coordination.

The nationally prioritised focus areas are presented below in **order of priority**. Within each of the areas, examples are given of topics in which N&N can be significant for technology and industrial development. The examples are not prioritised, since international scientific and technological development happens rapidly and demands a dynamic angle of attack. Prioritisation within sub-areas must therefore be dealt with during the implementation with the aid of standard criteria for scientific quality. Prioritisation of the individual research project must be done on the basis of strategic choices combined with stringent requirements for competitive scientific quality. Choice of areas for heavy investments in the field of N&N must be made on the basis of certain general preconditions:

- The presence of industrial, raw-materials or expertise advantages
- Technological capability for breakthroughs, new products, or new wealth creation
- N&N anchorage in milieus that already possess a high level of relevant expertise
- The will and ability to draw on national infrastructure and platforms whenever essential
- Suitable management for projects of an interdisciplinary character

Energy and the environment

Objective: Norway shall become a world leader in the field of N&N for energy systems. Norwegian industry shall choose to become suppliers of relevant technology on the basis of N&N.
Measures: Highest priority shall be given to energy and the environment among the thematic N&N programmes. Addressing breadth at the same time as focusing on selected topics.

Norway is internationally a leading energy nation, and our welfare and competitiveness depend to a large extent on energy-related activity. Hydroelectric power, oil and gas are national advantages, and there exist strong research and technology milieus.

At the same time, energy supply is intimately connected to local and global environmental effects. Globally, the obtaining of enough energy for a growing world population is probably the biggest challenge facing our civilisation in a relatively long-term perspective. Norway has an unusual opportunity to exploit its advantages and its technological position and at the same time attain agreed political objectives, by developing nanotechnology and materials technology for energy and the environment. A realistic ambition is for Norway to become a leading player in renewable and eco-friendly energy technology. Nanotechnology may also contribute to a better understanding of how material properties are governed from the atomic and molecular level, via the micro scale, up to the macroscale. More eco-friendly products may thereby be manufactured with a smaller consumption of energy and reduced discharges and emissions of environmentally hazardous substances.

The following areas will be particularly promising for a strong Norwegian participation:

- Gas conversion
- CO_2 capture
- Petroleum production
- Solar panels
- Hydrogen technology
- Batteries and energy harvesters
- Increased energy efficiency (industry, homes, transportation)

ICT including microsystems

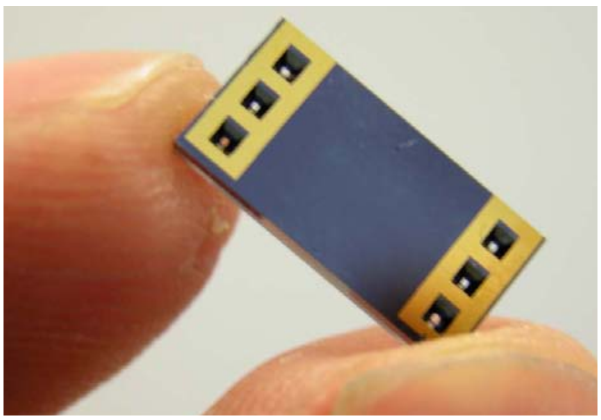
Objective: Norwegian research communities shall be among the foremost in Europe in at least one area within ICT/microsystems. Norwegian industry shall make effective use of nanotechnology in combination with other advanced technology in ICT products.
Measures: A focused investment in selected areas of nanotechnology in combination with other advanced technology for ICT/microsystems.

Information and communication technology affects practically all societal areas. The technology development has been driven by the need for smaller, faster and cheaper computers. In recent years the most important driving force has to a large extent concerned extended functionality. Research in the EU's IST programme has been focused on the paradigm "ambient intelligence". This entails a development in the direction of miniaturised, autonomous, distributed systems that perform measurements, signal and data processing and that communicate with the outside world. Such a development demands the creation of technology for:

- Microprocessors, data storage and electronics with extremely low power consumption
- Advanced micro-sensors
- Wireless communication
- Distributed miniaturised current sources (energy harvesting, micro-fuel cells, batteries)

In Norway there are no industrial locomotives producing integrated circuits and microprocessors. What we do have, on the other hand, is several companies that supply microsystems and microsensors. Future sensor technology and autonomous systems will be key elements for considerable parts of Norwegian industry. An example is the enormous need for processing, structural and condition monitoring in the oil and gas industry when it switches to unmanned operations, ventures out into great ocean depths and expands into the High North. The area is also important for other research and industry in Norway, e.g. related to space exploration and particle physics (CERN).

A Norwegian nanotechnology programme will focus on:
- Nanomaterials and nanocomponents for electronics, data storage, optics, sensors, actuators and radio frequency components.
- Integration of nanomaterials in sensors and actuators (mixed technologies)
- Nanostructuring
- Nanofluidics



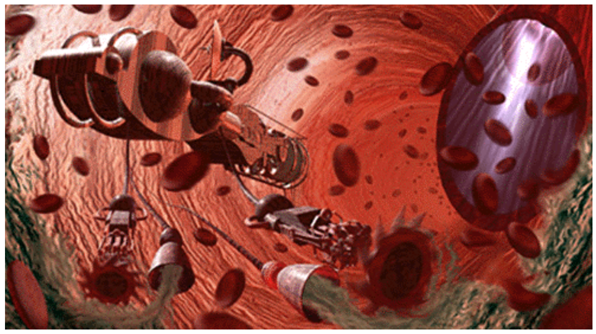
MICRO-VALVES: ICT and mechanics combined on small silicon chips offers high precision. Photo: Micostaq

Health and biotechnology

Objective: Norwegian research in bioN&N shall become an international leader in niches for development of new materials and strategies for advanced prevention, diagnostics and therapy.
Measures: Focused investment in order to strengthen interdisciplinary cutting-edge expertise on the basis of established communities. New activity shall be developed within selected niches via young researchers or foreign recruitment.

Roughly speaking, BioN&N comprises two areas. The one is directly relevant to health and welfare and covers regenerative medicine such as medical implants, cell and tissue culture, nanomedicines, diagnostics with new sensors and biochips plus imaging inside and outside the body. This area is prioritised in the EU's seventh framework programme through the technology platform "nanomedicine".

The other area comprises biomimetic materials and biological interfaces in connection with maritime climate and foodstuff production.



NANOROBOTS in the circulation of blood can keep the vessels open, monitor the health, or fight against disease. Ill: Julian Baum/Foresight.org

A common basis is understanding of structures and processes in living organisms such as proteins, DNA, subcellular structures, cells and tissue structures, at molecular level. The basis includes methods for analysing and affecting. Some of the most important driving forces in the development of bioN&N are the revolutionary mapping of genomes, the development of organic synthesis of complex bioactive molecules, and the convergence with materials, micro and N&N.

Applications of N&N in clinical diagnostics, medical components including implants, tissue generation and pharmaceuticals will increase sharply in the next few years. N&N will contribute to medical revolutions such as radically new strategies for target-seeking cancer treatments, nanorobots for vascular surgery and functional biomaterials for tissue regeneration and creation of new tissue (tissue engineering). The combination of better target-seeking pharmaceuticals with better diagnostics will probably lead to more effective individualised treatment with fewer side-effects.

Norway has several advantages in the health and biotechnology field such as its extensive medical registers and unique biobanks that can be exploited positively. Techniques at the nanoscale for measurement of reactants will be necessary in order optimally to exploit the biological material in Norwegian biobanks. Specific use of bioincompatibility for therapeutic purposes is a field with strong Norwegian expertise. Cooperation and synergy with the FUGE programme is necessary if the Norwegian resources are to be used optimally. Among the many possible areas in this field, some appear particularly promising for Norway:

- Biocompatible materials
- Sensors, diagnostics
- Drug delivery

At the same time, ripple effects are expected in fields such as immunology, neurobiology and cell and tissue cultivation.

Ocean and food

Objective: Norwegian business interests shall be international leaders in the application of N&N to aquaculture and shipping.
Measures: With a point of departure in competent communities in Ocean and food, networks shall be established that can exploit breakthroughs in the field of N&N and utilise them in products.

Aquaculture is an important Norwegian industry, particularly in the regions, and has a great growth potential. The industry must, however, become better at building upon fundamental research if it is to safeguard continued expansion in a sustainability perspective.

In the rest of the food production and shipping sector, N&N can contribute to solutions in several areas when the technology is combined in a smart manner with other advanced technologies.

This is currently an immature field with a relatively weak connection to N&N. The potential is, however, great, and several areas may be important for Norway in the somewhat longer term. Examples of interesting areas are:

- Tracing of food
- Smart packaging
- Food monitoring
- Surface treatment
  - o reduced algal growth and fouling of ships and offshore installations
  - o reduced bacterial growth in food production facilities

What about other areas?
Since nanotechnology is a generic or facilitating technology, most of the development in the abovementioned areas will also be important to other fields. Tool platforms and expertise areas that are common to the focus areas will also be important for new areas for wealth creation and for new scientific insight.

Spin-off effects that cannot be predicted today are expected as a result of this strategy. The Research Council of Norway should have a preparedness system to detect such effects. Expertise areas that are common to the prioritised focus areas, and which will contribute to such effects, are described below.

Expertise areas

Objective: Establishment of a focused and interdisciplinary knowledge platform so that N&N will yield new knowledge and increased understanding of materials, systems and processes, and will create the basis for innovation and new wealth creation on the basis of nanotechnological applications in industry.
Measures: A broad investment in generic expertise areas and establishment of networks on the basis of objective quality evaluations.

Nanoscience forms the basis for the nanotechnological applications presented in the previous section. However, an investment in nanoscience is also important to achieve progress in scientific insight. The significance of fundamental new discoveries and theories in natural science ought not to be underestimated. Quantum mechanics and relativity theory are our age's monuments of discovery. They are the results of fundamental research, achieved partly by individual geniuses and partly through cooperation in good research teams. Even if the theory of the individual elements of nanoscience (atoms and molecules) is well-established, there is a considerable potential for f**undamental new understanding** in N&N. We currently suffer from deficient understanding of the transition between pure quantum-mechanical and classical systems. Nor do we understand phenomena such as complex systems and how individual molecules organise themselves to produce life and consciousness. N&N is a very central and important research arena for such questions, since the functional molecules of life are to be found at the nanoscale.

Internationally speaking, N&N currently has a strong character of basic research. It will develop new, generic knowledge and increased insight into fundamental phenomena. At the same time, our expectations of applications are great, and thereby also the focus. In many areas it is a short distance from basic research to application. This means that traditional, linear models of knowledge development and division of labour are no longer suitable; for example, the universities, colleges and institutes are all important contributors to nanoscience research. It is therefore important to create communities in which basic research and applied research can cross-fertilise one another. The proposed strategy reflects this basic outlook. The strategy facilitates an integrated mixture of needs-driven research through thematic priority areas and knowledge-driven research through expertise areas and tool platforms. In the figure on page 25, this means that knowledge will flow both upwards and downwards.

The quest for new knowledge leads to new, often unforeseen, applications. Research at the cutting edge of nanoscience demands especially strong and expensive tools for creating, manipulating, measuring, characterising, modelling, understanding and using materials and components with dimensions at the nanoscale. This has clear interfaces with the conventional disciplines, particularly chemistry and physics. The application potential of nanotechnology is great, but in an introductory phase the basic research aspect should be paid the greatest attention.

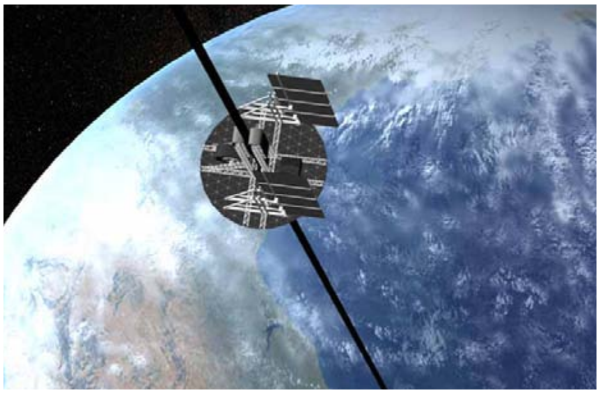
The preceding proposal creates space for **fundamental** and **long-term** research through the expertise areas and the tool platforms presented below. In addition it is emphasised that the Research Council of Norway's traditional instrumentalities for fundamental research, such as researcher projects, must be available for smaller scientific milieus of high quality, both through the N&N programme and through other instrumentalities.

It is crucial for an optimal development of N&N in Norway that a sufficiently heavy and broad basis be developed within disciplines of a generic character. These will be important in the great majority of relevant fields within nanotechnology. The associated expertise is extremely important for N&N and to trigger new wealth creation related to the thematic priority areas. It is proposed that the following expertise areas be prioritised:

- Materials
- Interface/surface science and catalysis
- Fundamental physical and chemical phenomena and processes at the nanometre scale
- BioN&N
- Components, systems and complex processes on the basis of N&N
- Ethical, legal and societal aspects, including health, the environment and safety

Materials

Materials are a very central key technology, whether we are talking about nanoparticles, thin films, alloys, composites, hybrid structures, biomimetic systems or biomaterials. Design of such materials, perhaps assembled in composites, components or nanostructures, will constitute the core of new, nanotechnological products.



SPACE LIFT: New carbon based materials may become strong enough to support a space lift attached to the earth. Photo: HighLift Systems

Norway has strong technological traditions and a high degree of wealth creation related to materials. New products on the basis of nanostructured materials can be anchored here. Through their physical, chemical and mechanical properties, materials have an enormous significance for society and technologies. They are used for structural purposes in the widest sense and to give components a functional property on which application is then based.

The properties of materials derive partly from their atomic number and weight, partly from how the material is structured (nanostructure). New solutions in various technologies for energy, the environment, bio and ICT often possible only through developing new materials with radically improved properties. These are currently expected to come to a large extent through nanostructuring. In addition, nanostructuring and connection of different materials at the nanoscale will it itself give rise to new properties, some of them quite unexpected. Development of materials and nanotechnology are thereby intimately linked together, and development of both will trigger other societal technologies [the Research Council of Norway 2005].

Interface and surface science and catalysis
Every material, component or object has external surfaces and internal interfaces. When the size goes down as drastically as to the nanometre scale, the ratio between surface area and volume becomes extremely high. The surface acquires great importance for nanostructured objects. The composition of, morphology of and defects in the surface may determine electrochemical and mechanical properties in catalysis, corrosion, wear resistance and energy conversion. The surface also determines properties such as biocompatibility and biofouling. The implementation of N&N in new products within the thematic prioritised areas requires profound knowledge of interface and surface science, including the ability to design, produce, characterise and understand properties at a fundamental level. Increased understanding of the interfaces between inorganic, organic and biological materials are important to achieve synergy between material, bio and medical technology.

Catalysis is about making chemical reactions happen more quickly or at lower temperatures, which means lower energy consumption. The objective is to achieve high conversion, few by-products and little pollution. In biological systems enzymes (proteins) control the breakdown and reconstruction of organic molecules. They are absolutely essential inter alia in photosynthesis and the vital functions of the cells. Catalysis is used in many different technologies and processes in oil and gas conversion, onshore chemical industry, purification technology and energy technology. Use of nanotechnology will both improve existing catalysts, give us wholly new catalysts for new purposes, and open the way to rational design on the basis of atomic insight. A vision in catalysis research is to develop catalysts that are just as effective and selective as enzymes, and at the same time more robust.

Fundamental physical and chemical phenomena and processes at the nanometre scale
The physical, chemical and mechanical properties of a material are dependent on the size and structure of the particles at the nanoscale. This is central to the study of fundamental phenomena and processes (mesoscopic physics and chemistry).

In order to study such properties at the nanoscale, measurements must be undertaken of individual particles and components, which demands advanced and specialised measurement technology and visualisation. It is precisely at this order of magnitude that particles and components acquire properties that make nanotechnology such a powerful tool. Here we need the development of new theoretical understanding, particularly in mesoscopic physics. Key areas are decoherence and controllable quantum processes, phenomena related to special interactions, pressure and temperature plus self-organisation and complex dynamics.

BioN&N
The term “bioN&N” includes a great number of phenomena, methods and structures exploiting nanotechnology for biotechnological and medical applications. Examples are nanostructured implants, structures for cell and tissue cultivation (tissue engineering) and nanomedicines. Nanoparticles are used as target-seeking drug vectors. Other applications are biosensors and various diagnostic tools. Tomorrow’s biomatrices and “laboratories on a chip” will exploit nanostructured surfaces and immobilised biomolecules to make powerful clinical diagnoses and treatments. Magnetic nanoparticles can be used for the same purposes and also for precise imaging in conjunction with NMR. Biomimetic systems may include biomembranes and subcellular components that imitate their biological equivalents in cells and cellular communication.

Components, systems and complex processes exploiting N&N
Components (devices) such as sensors, actuators and integrated circuits with specific functions will to an ever-increasing degree be used in medicine, ICT, electronics, safety, oil production, process control and industry in general. Developments have accelerated in consequence of breakthroughs in microtechnology. In future, nanocomponents will take over as the active components.

Processes with technological steps such as separation, membrane technology and filtration, are to a large extent used in the oil and gas industry, onshore chemical industry and energy technology. Optimisation and miniaturisation of the processes will be considerably indebted to nanotechnology.

Fluidics is about how the flow properties of a liquid are affected by nanoparticles or by nanopores and nanochannels. Etching and lithography techniques are well-suited to creating networks of channels at the micro or the nanometre scale. They can be used in chemical, biochemical or biological applications – from tools for synthesis (nanoreactors) or analysis to sensor systems and energy technology (e.g. microreactors for portable electronics). Properties of fluids and their interactions with surfaces at the nanoscale are of increasing importance.

Optics and laser technology are undergoing breakneck development, with ever shorter and more intense laser pulses. Attosecond laser sources with extremely short wavelengths will probably become established as the new microscope technology. Alternatively, new imaging techniques can be developed on the basis of multiphoton processes. Design of nanostructures with special emission and absorption properties can have significance for areas ranging from sensor technology to lighting. Individual photons can also be used for information processing and transport.

Ethical, legal and societal aspects
Knowledge of how nanomaterials affect health and the environment is incomplete. The Research Council of Norway's report on nanotechnology and health, the environment, ethics and society [the Research Council of Norway 2005(f)] points to several important issues with ethical, legal and societal aspects, including health, the environment and safety. Research and expertise development in this field is necessary if we are to understand to what extent and how N&N is a common good, and how it can be put to use safely and without harmful effects on health and the environment. Important research tasks will be studies related to the properties of materials, long-term effects and possible toxicity for health and the environment. N&N is also surrounded by many ethical questions, for example in connection with medical applications, which can be disturbing for and challenging to society. See also pages 16 and 17. Such questions should be given plenty of space in a unified N&N programme.

Tool platforms

Objective: Relevant, competitive and available tools for N&N related to the thematic priority areas and expertise areas.
Measures: Establishment of networks for the various tool platforms.

Synthesis, manipulation and fabrication
Oversimplifying, we might say that in order to discover something new, one must first make something new. This is particularly relevant in the N&N area. Scientists must therefore master tools for synthesis of nanomaterials, nanostructured surfaces and nanoparticles plus fabrication of components and structures in which nanodimensions have a central place. Through network measures, different research teams should have access to methods and expertise in tools for synthesis, manipulation and fabrication. Some of these the activities must be carried out in dedicated clean rooms.

Characterisation
Advanced tools for characterisation are required to study static and dynamic properties (chemical, physical, mechanical and biological) at the nanometre scale. If the equipment does not exist in the Norwegian research system (not commercially available, too demanding on infrastructure or too expensive), access should be secured via international cooperation and agreements. Nationally, broad access should be secured through establishment of networks for characterisation.

Theory and modelling
Theory and modelling tools are an essential and integrated part of projects in N&N. Advanced computers and suitable computation software are becoming ever more vital. Number-crunching and graphic manipulation are decisive for the understanding of properties at the nanoscale. Access to satisfactory number-crunching resources is therefore necessary. These can be developed with prioritised public instrumentalities.

Many fundamental phenomena at the nanoscale are still poorly understood. Development of fundamental understanding must thereby have a central place in a long-term nanoscience programme.

Instrumentalities

- *A focused and strategic funding of communities and projects of particularly high quality and any special resources (major projects) should be introduced.*

- *Two national infrastructure centres and a number of tool platforms should be established as part of networks for national infrastructure for N&N. These should be given long-term funding, subject to national coordination and obliged to offer national accessibility.*

- *In order to lay the foundations for exploitation of N&N in industry and to support N&N within the thematic priority areas, industry must be given access to national infrastructure for N&N.*

- *We should invest in individual-based funding (international postdocs, recruitment posts, guest researchers, starting packages) with a view to importing international impulses, building new expertise, giving young researchers better conditions and strengthening recruitment.*

- *Measures should be evaluated in order to ensure that the instrumentality apparatus for innovation and commercialisation is optimally exploited and contributes to encouraging good, commercialisable N&N ideas.*

- *In order to have good continuity through the chain from ideas and basic research to products and commercialisation, there must be instrumentalities for applied research, both with and without company participation. We should invest in patenting and other safeguarding of intellectual capital as a basis for commercial exploitation.*

- *Higher standards of expertise in research management are expected for interdisciplinary projects involving both basic research and industry-related activity. Training facilities should be addressed through general measures.*

In addition to scientific content, the way in which the programme is organised and implemented is decisive to our success in an internationally competitive field with great potential for science and wealth creation. The strategy draws up guidelines and frameworks for the scientific programme, but cannot specify all the details. In this and the two subsequent sections, therefore, a model for organisation of N&N programme and a number of project, individual and infrastructure-oriented instrumentalities are described, together designed to ensure an efficient implementation of the programme.

Infrastructure and coordination

Objective: To use established and new infrastructure facilities as national resources with a high degree of accessibility for N&N. High degree of scientific and methodological knowledge in generic N&N fields.
Measures: To establish two laboratories as national infrastructure centres for N&N. Identify and develop a number of tool platforms based upon their in special advantages within niches for the scientific host communities, and organise these in networks.

In the section “Coordination” on page 20 it was argued that investment in infrastructure, laboratories and instruments for N&N should be coordinated nationally. Important reasons for this are the high investment and operating costs (and thereby requirements for a high degree of exploitation), the need for well-qualified personnel and good availability to research and education institutions, the institute sector and industry.

By far the biggest current investments in N&N infrastructure in Norway are MiNaLab/SMN in Oslo and NTNU NanoLab in Trondheim. These have been or will be supplied with funds from the respective universities, SINTEF, the Research Council of Norway and the Ministries. These are investments in the order of magnitude of many hundred million kroner. The two institutions are obvious candidates to be assigned a role as national infrastructure centres for N&N. Since such a role demands that the laboratories be made generally available, we cannot, without any dialogue with the responsible institutions, propose that these be designated to perform national missions. It is therefore proposed that the Research Council be commissioned to coordinate the initiation of such centres under current guidelines. The national resource role of these centres involves a number of demands made on the host institutions:

- The allocation shall make it possible to offer access to the infrastructure for a small fee.
- The allocation of user time shall be on the basis of applications and quality evaluations.

- The infrastructure shall be operated and maintained in such a way that external users gain access to optimally-run laboratories with personnel who will assist in the experiments and who possess a high degree of methodological expertise.
- The laboratories shall be really available for others than the host institution. The national resource status presupposes that external use exceeds a certain operational percentage.
- Practical resources for visiting researchers must be made available.
- The laboratories should be stimulated to research of both an applied and a basic character, and equipment should be available that can bring (basic) research up to demonstration level.
- An effort should be made to ensure that the laboratories are complementary.

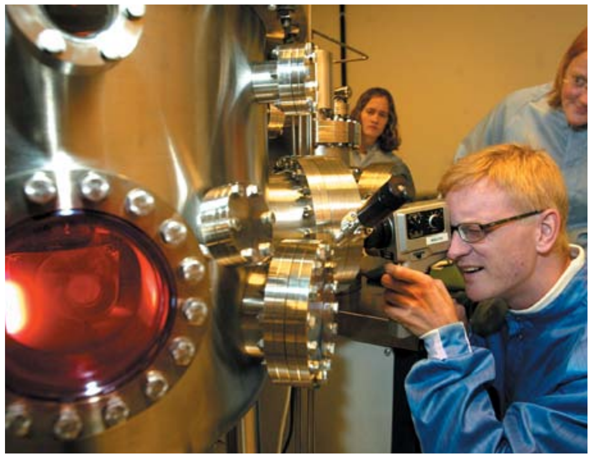
In return, the laboratories are offered predictability and funds that enable good and sound operation:

- They should be promised long-term funding of operation and renewal of the laboratories.
- They should be promised long-term funding of essential technical personnel and any methodological specialists.

In addition to the two above-mentioned resource centres, several institutions possess highly-qualified laboratories and high-level expertise in niche areas, but on a considerably smaller scale than the operations in Oslo and Trondheim (see Appendix 1). Since N&N is an important and growing field, it is important to offer a good and suitable instrumentality apparatus for the rather smaller N&N players, not least in order to secure recruitment and local expertise. The way is therefore opened for nationally-coordinated tool platforms. These should be established on the basis of open calls for proposals, with scientific quality and methodology as the decisive criteria. If the scope or needs make it appropriate, it should subsequently be considered whether these should be given status as national centres. The precondition for establishing new activities is that there is a great need or demand for services that are not met by existing facilities. Detailed decisions should be made on the basis of the proposed coordination and call-for-proposals process led by the Research Council of Norway.

It is proposed that the national infrastructure centres and the tool platforms be organised as a network, in which users are registered and apply for user time at the different facilities. Allocation of user time is in accordance with an external quality evaluations subsequent to applications.

In some cases it will be natural to collaborate with other programmes, for example FUGE, on infrastructure or equipment. The initiative for this and the organisation of the collaboration shall be done by the Research Council of Norway.



INSIGHT INTO NANOTECHNOLOGY: Advanced laboratories enable new knowledge of materials' properties. Photo: NTNU

Major projects and strong research communities

Objective: To develop research communities that can assert themselves internationally.
Measures: Focused and strategic funding of projects and communities that distinguish themselves by a particularly high expertise and quality.

Given the high degree of interdisciplinarity in N&N and the desire to achieve synergy between long-term basic research and applied/ industrially-oriented research, in the section "Coordination" on page 20 it was recommended that we create scientifically strong, robust communities with the capacity to conduct long-term basic research, applied research and industrial cooperation in one and the same milieu. The working party therefore proposes that a substantial share of the resources be spent on major projects that can create strong, robust research communities with a sufficient critical mass to undertake such simultaneous tasks. This may be local milieus that are big enough in themselves, and when supplied with funds achieve a robust size. It may also be axes or alliances that by combining can meet the requirements of a strong research community.

Many possible balances between basic and applied research can be envisaged in such projects, depending on the degree of industrial maturity and applicability of research. Individual projects can be very fundamental whereas others may have a much higher degree of applied research and industry participation. Major projects may be found within both expertise areas and thematic priority areas. Such projects and communities will be important resources for education on different levels.

A precondition for robust communities is **long-term and predictable funding**. From being extremely application and evaluation-based, it is therefore recommended that some of the funding be strategic, with evaluations on the basis of results. Scientific milieus with strategic funding will be required to meet a set of criteria in the course of a stipulated time:

- The research is of a high international quality (as measured on standard criteria).
- The milieu has activities in basic research.
- The milieu has clear elements of application of results and innovation, for example via collaboration with industry, patenting of research results or start-up of companies.
- Activities in ethical, legal and societal aspects, including health, the environment and safety, are integrated into the milieu.

It will also be natural for the milieu to participate actively in tuition and international cooperation.

On the basis of objective criteria for quality and performance appraisal, the strategic funding of major projects **should be increased or reduced** at regular intervals. These are partly standardised scientific criteria (publications, citations, invited lectures), partly innovation-relevant criteria (patents, start-ups, industrial cooperation). Major projects must always be appraised by independent international expertise that considers quality and target achievement, both on start-up and in the follow-up phase.

Individual-based instrumentalities

Objective: Preparedness and capacity for research dynamic through drawing on international trends and expertise. Recruitment of outstanding students and researchers.
Measures: Special focus on individual-based funding: international postdocs, recruitment posts, guest researchers plus starting packages for young researchers.

Human capital is vital to the development of new research areas. Students and young researchers feel attracted to N&N, and it is essential to offer them resources and tenure tracks. At the same time, it may be necessary to import the relevant expertise from abroad so as rapidly to be able to develop robust activity around the prioritised areas. Development of cutting-edge expertise in prioritised areas must be balanced against any needs to open up new areas of N&N. For these purposes the following measures are proposed:

- **International postdoc fellowships**. These should preferably be used for research visits at the top research institutions abroad, the objective being to bring home valuable knowledge.
- **Recruitment post**s for young researchers shall make it attractive to come home from international research visits. We must facilitate appointments that help to make tenure tracks visible and thereby enhance recruitment.
- **Attractive funding of** guest researchers and a good research milieu should be deliberately used to attract competent researchers for longer or shorter stays at Norwegian institutions.
- In order to attract top researchers from abroad to new, permanent posts in Norway, we propose to introduce external funding of **starting packages** for outstanding new researchers.

It is a major challenge to ensure that scientific quality, competitive infrastructure and instrumentation, good opportunities for external funding and a good milieu, make Norwegian universities attractive.

Innovation and industrial development

Objective: Increased innovation, increased wealth creation in existing industry, and start-ups on the basis of N&N.
Measures: To facilitate the optimal exploitation of the instrumentality apparatus for innovation and commercialisation. To introduce instrumentalities for applied research with and without industrial participation. To focus on patenting as a basis for commercial exploitation. Actively to work on the creation of meeting-places between industry and academia.

In N&N there can be very short and very long time-scales from fundamental research to innovation. This makes big demands on the instrumentality apparatus.

Parts of N&N research are oriented towards nationally prioritised areas in which the potential for innovation is great. Radical technological breakthroughs may form the basis for large-scale new wealth creation. This requires expertise and consciousness-raising in the instrumentality apparatus and industry, and the will to invest heavily in niche opportunities.

N&N is already integrated into parts of industry through processes and products (mechanical strength, wear resistance, barrier properties, contrast agents, sensor materials, microsilica etc.), but technology development has not been founded on fundamental, conscious N&N. Industry must be invited to **collaborate** regarding N&N areas, so that it can strengthen its own expertise and set up projects with scientific partners. Contrariwise, in some cases it may be natural for industry to invite the collaboration and make its resources available.

It is assumed that funding will generally go through the usual channels for user-managed research, such as user-managed innovation projects in e.g. BIA, SkatteFUNN and in a new N&N programme. In addition, an industrial component will be supported via major projects as proposed in this strategy.

The big industrial nations and many big companies are extremely active in **patenting**. This can block Norwegian commercial investment and exploitation. It is important to get our own patents in the areas where we are endeavouring to lead the pack.

In order to facilitate enhanced cooperation between academia and existing industry, it is proposed to make N&N laboratories and heavy infrastructure available to industry on the basis of rules for free competition. This will effectively allow for new N&N products from established industry and create an important basis for the establishment of new companies.

N&N will be the origin of a number of new, commercialisable **products**. To a large extent these will emerge out of institutions with heavy activity in the field. These institutions already have a system for commercialisation. However, instrumentalities for verification, product development and start-up of new SMBs, probably over and above what is available today, will also be important. If institutions are to be able to a greater extent to follow ideas and products towards commercialisation, instrumentalities should be created for applied research without necessarily requiring company participation. That is, establishing supplements to present-day schemes that require company participation (KMB and BIP). These must also be reconciled with the rules for free competition.

Another instrumentality for existing SMBs is to offer external assistance in identifying and concretising N&N opportunities and ideas that will give the companies new innovation capability.

Research management

Objective: A high degree of expertise in research management of interdisciplinary projects and projects in which both basic research and industry-related research are included.
Measures: Offer of training in research management. To be addressed through general measures.

The proposed major projects involve a need for a new type research management for inter-disciplinary projects, with the capability to develop synergy between fundamental and applied research, including innovation and contact with industry.

The responsibility for scientific management should primarily lie with the institutions. The Research Council of Norway should supplement this with an offer of training in research management. This may include project management and project budgeting, personnel responsibility, knowledge of the EU system, media training, research ethics, research policy and research funding, negotiation expertise, knowledge of intangible rights (IPR), start-up of companies and growth investments (venture capital).

In order to strengthen the role of research manager in N&N, it is proposed to create meeting-places for research managers under the aegis of the Research Council of Norway, for example in connection with scientific conferences.

Organisation of the priorities

- *A focused and long-term (at least 10 years from 2007) N&N programme should be established. Research in the field of N&N should be funded via existing programmes for the thematic priority areas and through a focused "New Nano Programme".*

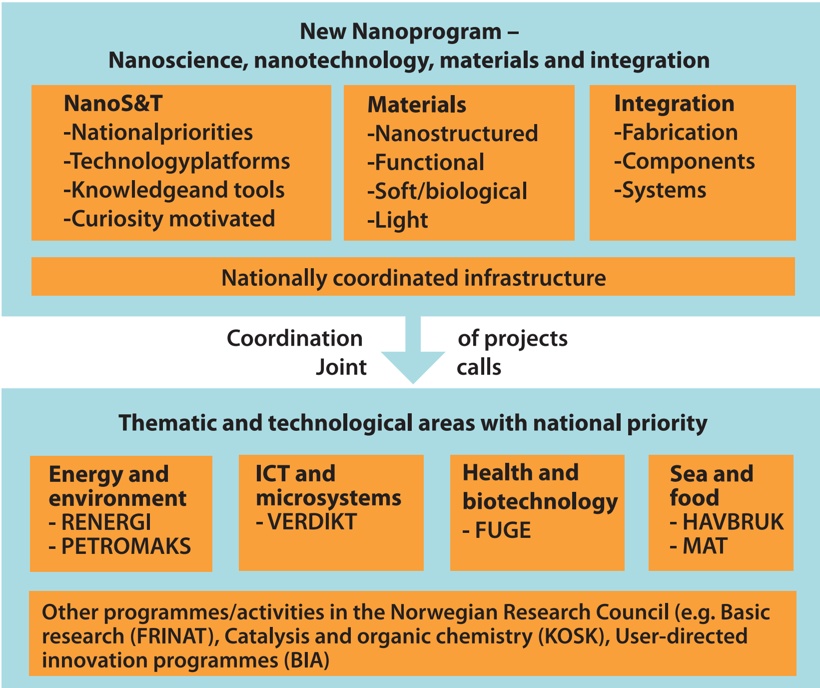
Objective: A long-term, focused investment in N&N shall provide an expertise basis for increased and new Norwegian wealth creation based on N&N.
Measures: To establish a coordinated and long-term (at least 10 years from 2007) programme with its point of departure in a "New Nano Programme", which shall interact with instrumentalities for nationally prioritised thematic and technological investment.

The model in the figure below has similarities with the NMP programme in the EU's sixth framework programme (thematic priority area 3; Nanotechnologies and nano-sciences, knowledge-based multifunctional materials and new production processes and devices). It differs from the NMP programme by having a greater focus on basic research. This is natural and essential since the basic research component of N&N in the EU is to a large extent left to national research councils.

The working party has considered whether it would be expedient to propose the establishment of a pure N&N programme, or a broad spreading of resources over various instrumentalities and programmes, with or without a coordinating responsibility assigned to one of the programmes. The main argument for not establishing a separate N&N programme is that N&N borders on and includes so many different disciplines, technologies and applications that natural demarcations, for example against functional materials or microtechnology, will be difficult to find. Instead, the Norwegian investment in N&N, as in the EU, should be made as part of a broader technology programme with a focus on expertise areas. Funds are allocated, and if necessary coordinated, through the calls for proposals, with N&N funding of thematic prioritised areas (applications). The model corresponds to the focused investment model described in "Coordination" on page 20, that is, that Norwegian N&N is funded both through a program with expertise responsibility for N&N and by instrumentalities oriented towards the national thematic priority areas. The current NANOMAT programme is considered to be a good candidate for extension in the direction of a broader technology programme. In this way we can directly draw on the expertise that has already been developed within the materials area that is so important for N&N. It also contributes to visibility.

Since the proposed organisation of the programme differs from NANOMAT's in several key areas, we will here call the new programme, which includes N&N, materials and integration, by the name of **"New Nano Programme"**. It is proposed that this programme have the funding responsibility for infrastructure and expertise areas in N&N, and for relevant curiosity-driven research. The programme shall in addition fund fundamental research within the thematically prioritised areas, through major projects and through current application types in the Research Council of Norway. This will mean a growing share of user-managed innovation projects.

The programme must be **long-term** if there is to be realism in the visions of a basis for new wealth creation and in order to secure predictable conditions for the national infrastructure centres. It is



Suggested organization of research into nanoS&T in Norway

recommended that the programme last at least from 2007 to 2016, and that a continuation be considered and if necessary planned in good time before the period is over.

The N&N programme must have optimal **interfaces** with associated technology areas, particularly those that have been important pillars in NANOMAT. The working party strongly recommends that the "New Nano Programme" also include materials research that cannot in itself be described as quite being N&N, and that integration of nanotechnological components be given a more visible place than today. "Integration" is important in order to address research challenges so as to make use of fundamental results. To a large extent this is a matter of methods for integration of new generations of functional, smart materials that interact with the outside world. These may be sensors, actuators, electronic, optical and biomedical components. The Research Council of Norway may also consider whether the "New Nano Programme" is to incorporate materials and methodological elements of microtechnology that are currently not covered by the focused ICT programme VERDIKT. Nor does this programme include N&N for ICT.

N&N must also be developed with an optimal mixture and collaboration between purely basic and applied research. The distance may be short from methodological development and curiosity-driven research to technological development and practical applications. It is necessary to ensure considerable and permanent knowledge-driven (basic) research. An open interface between science and technology is demanded to trigger new opportunities for wealth creation. This presupposes interaction with product development and commercialisation.

The proposed division of labour between the "New Nano Programme" and the thematic/technological instrumentalities in the Research Council of Norway makes **coordination** of the investment extremely necessary. It is proposed that responsibility for the coordination be entrusted to the "New Nano Programme", since it will be getting the responsibility for expertise areas, tool platforms and infrastructure. As with the recommendations from the Foresight report, it is recommended that the Research Council establish a coordination group for N&N (and materials technology) across division and programme boundaries.

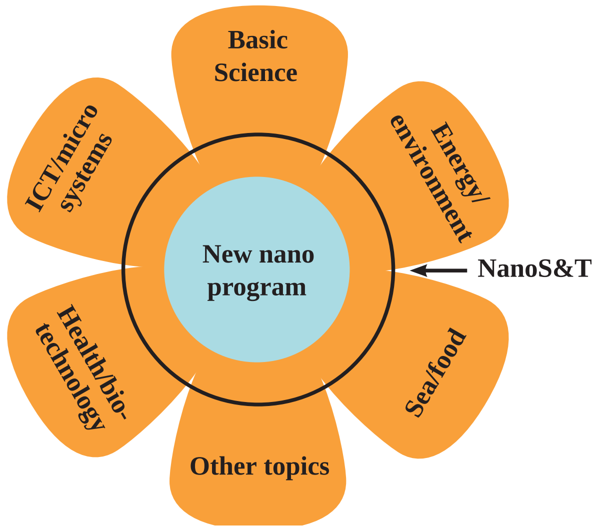
N&N represents a new technological dimension with great potential for radical development in disciplines and key societal technologies and thereby wealth creation. It is therefore of great importance to facilitate an optimal development of the field in Norway, particularly because of the resource situation and the strong international competition. It should therefore be considered whether in the long term a **national council** should be created, anchored in the Ministries, for coordination of N&N in Norway, somewhat similar to what exists for the hydrogen area.

It is proposed that N&N for nationally prioritised thematic and technological areas be implemented through established instrumentalities. It is also recommended here at N&N and new materials be seen in close proximity. The "New Nano Programme" will have basic activities oriented towards the thematic priority areas, and it is proposed that it be assigned a paramount **coordinating responsibility**.

If suitable programmes that can host N&N oriented towards thematic and technology areas in the White Paper on Research do not exist, the responsibility and resources for this research should also be vested in the "New Nano Programme".

Should NANOMAT be given the role of the "New Nano Programme", the organisation of the programme, including Board representation, must be carefully reviewed and adapted to the new and demanding assignments.

It is emphasised that an investment in N&N must not occur at the expense of associated areas, for example other materials research, physics or chemistry, which forms a basis for N&N. Existing, good communities in these subjects neither can nor should be expected to develop new N&N activity without the injection of new resources, from both external and internal sources.



"New nano program" will support research within nanoS&T (inner circle) and other topics (not shown in the figure.) NanoS&T is also supported by other programmes/activities in the Norwegian Research Council (within the outer circle). Significant parts of the activities financed by the New nano program will thus support the Norwegian thematic priorities.

Interaction between different players

- *International networks must be strengthened through network-building funds.*

- *Education and researcher training in N&N must be further developed in order to secure access to students and researchers. Measures for international recruitment must be considered, particularly in order to satisfy needs in the short run.*

- *N&N should become part of a national dissemination strategy.*

- *Ethical, legal and societal issues (ELSA), including health, the environment and safety, should be addressed through integration of such issues into relevant projects (for example major projects), through the infrastructure centres and through special calls for proposals oriented towards ELSA. Research should be coordinated with corresponding initiatives in other fields by the Research Council of Norway.*

This chapter points to other key aspects of a successful N&N programme, particularly associated with international cooperation, innovation and industrial development, education and recruitment, dissemination, and ethical, legal and societal factors.

International cooperation

Objective: Close interaction between Norwegian and foreign research communities in N&N.
Measures: Funds for international network-building

Internationally speaking, investment in N&N and associated areas is on a very large scale. Norway has limited resources for research and infrastructure, and will probably account for less than 1% of international knowledge acquisition. International cooperation is essential; both in order to secure Norwegian research communities access to advanced equipment, new research ideas and participation in big international projects, and also so that Norwegian industry shall be able to inform itself and exploit new results.

The proposed N&N programme will lay a wholly necessary foundation for Norwegian scientific milieus being seen as partners in collaborative international projects. In addition, we must stimulate international research collaboration. In the foregoing we have proposed measures on an individual level. More concrete resources should be assigned to bilateral collaborative projects that the research institutions have set up with leading institutions abroad. International contacts on an individual level should moreover be encouraged, for example via increased funding for participation in international seminars and conferences.

The most important arena for international networks and collaborative projects is the **EU's** framework programme. For fundamental research, development and industrialisation of N&N alike, it is necessary that the institutions and the companies participate in networks, researcher exchange and projects under EU direction. The Research Council of Norway must strengthen measures such as advisory services, support for partner-seeking, dialogue meetings, funding for positioning (PES), the co-funding scheme (SAM-EU) and the Brussels office. Most important of all, however, is that the scientific milieus be sufficiently robust and competent to undertake assignments as partners and preferably coordinators. It is natural that the initiative be taken to create national fora that reflect the European technology platforms (ETP) in which N&N has a central place, inter alia ENIAC (nanoelectronics), NanoMedicine, EuMaT (Advanced Engineering Materials and Technologies) and the "Hydrogen and Fuel Cells Technology Platform". Research institutions should be stimulated to helping Norwegian industry to participate in activities within the EU's framework programme wherever N&N is a topic. This is in line with the proposal in the section on major projects.

Norwegian research communities must continue to be ensured access to big experimental installations (Large Scale Facilities), including synchrotron radiation (hard and soft x-rays) and neutron radiation.

Education and recruitment

Objective: Attractive educational facilities that draw in and supply a satisfactory number of good candidates for research, industry and society.
Measures: To develop and refine attractive educational tracks in N&N.

Recruitment of Norwegian students to the Ph.D. course and candidates to postdoc positions in the relevant subjects is currently not very satisfactory. Thus it will continue to be for the foreseeable future, that is, over five years, on account of study choices already made. This will be a major challenge for how N&N is to benefit Norwegian society and industrial development.

In order to meet the challenge, the working party recommends a twofold approach: in the short run a strategy should be developed to **import skilled candidates** from other countries. These may be master's students from the EU, whereas Ph.D. and postdoc candidates must probably to a large extent be fetched from outside Western Europe. In order to attract the best candidates, it is recommended that the Research Council of Norway create the basis for an offensive recruitment policy vis-à-vis the rest of Europe and Asia through specific cooperation agreements at a national level with leading universities and research institutions.

In the long term this is not a tenable situation. It is very positive that Norwegian universities are now creating attractive **educational tracks in N&N**. The number of applications to the NTNU's course in nanotechnology in 2006 was most encouraging, and in accordance with the prophecies that N&N can become tomorrow's recruitment argument for science subjects, just like space travel was back in the 1960s and 70s [The Research Council of Norway 2005]. The effect of the work on constructing educational tracks in the field of N&N in Norway will not, however, be seen until Ph.D. level in five to eight years, and at postdoc level three years after that.

In general it is absolutely essential, for N&N too, to enhance the recruitment basis for science subjects in the university and college sector through targeted measures at all levels of the school system, confer the recommendations in the NMT report [the Research Council of Norway 2006]. This involves a broad spectrum of high-quality educational facilities in the traditional disciplines (mathematics, physics, chemistry, biology).

N&N at the scientific institutions should to a large extent be managed and conducted by personnel with a deep insight into the discipline. This dictates the recruitment of younger researchers to leading posts, whereas established researchers to a certain extent will cover interfaces with existing expertise and technology. Restructuring and new recruitment is important for a successful, long-term implementation of N&N in Norway.

Dissemination and dialogue

Objective: To give the population a balanced picture of the opportunities, challenges and any risks involved in N&N.
Measures: N&N should be part of a national dissemination strategy for science subjects and technology.

The population's knowledge of N&N is extremely uneven, and much of it is derived from science fiction or doomsday prophecies. It is important to avoid a polarisation of the debate about N&N, since this can make it difficult or impossible to introduce new technology, irrespective of the benefits to society. A good dissemination strategy will also improve recruitment to the natural sciences, and make it easier to get industry to play along. Moreover, a good dialogue with the population will clarify a number of the ethical and societal aspects of N&N.

It is therefore recommended that the Research Council of Norway create a national **dissemination strategy** for science subjects and technology. The purpose of this will be to provide a balanced picture of the opportunities and challenges facing us when introducing nano-products into society. This demands contributions from researchers and experts both from the technological milieus and from the ethical and social-science milieus available in Norway. An important point is to create contacts in the mass media. In addition, it may be sensible to involve laypeople as soon as possible, both in order to inform and to obtain impartial feedback from the general public.

Ethical, legal and societal aspects

Objective: To secure an ethical, legal and socially sound development of N&N.
Measures: Integration of ethical, legal and societal issues into the relevant projects and centres. Coordination of research in this field with corresponding initiatives elsewhere in the Research Council of Norway.

The ethical, legal and societal challenges (ELSA), including health, the environment and safety, as described on pages 16 and 17, must be followed up on all levels of the programme. Even today, such aspects of a project have been considered at the time of the application, but this is rarely followed up by concrete investigations or independent assessments of risk, toxicology etc. Such follow-ups and regular implementation of risk assessments must become a part of the projects wherever relevant, and be reported on the same basis as other results. It is particularly important in the development of commercial products. The strategy proposes that expertise in ethical, legal and societal aspects of N&N be related to the national infrastructure centres for N&N.

It is necessary to increase the general expertise in this field; both in order to be better equipped when technologies are introduced, and in other to be able to act proactively vis-à-vis concrete projects or product ideas. Proposals for pure projects in ELSA should therefore be called for.

The Research Council of Norway should coordinate scientific activity in ethical, legal and societal aspects with similar activities in associated areas, primarily biotechnology and ICT. They can lead to a **national centre** for such expertise. The centre will be able to coordinate research around materials and technologies in which Norwegian scientific milieus have advantages, and assist in research and reporting tasks for the public administration and industry. It can also help with dissemination on ethical and socially-relevant aspects to researchers, the public administration, industry and laypeople.

Budgetary proposals

- *Recommended overall framework for N&N: NOK 140 million in 2007, steadily increasing to NOK 280 million in 2016.*

- *70–80% of the total funds for N&N shall be channelled through the New Nano Programme, the remainder through other existing instrumentalities.*

The working party recommends a significant and long-term investment in N&N. This may become an important research element in the work of attaining the national goal of assigning 3% of GNP to research. In the long run N&N is expected to stimulate industry's investment in R&D, which is important if we are to achieve our paramount national research targets. In the consultation document for the national MNT strategy, it is recommended that Norwegian central government take the lead through strengthening the public appropriations for cutting-edge research in the MNT subjects. The working party's recommendations are further supported by the Research Council of Norway's Foresight study on materials and nanotechnology from 2005 [Research Council of Norway 2005]. This recommends that "NANOMAT shall be the Research Council of Norway's main programme in the next few years within nanotechnology, functional and new materials" and this investment in materials and nanotechnology should be increased from NOK 200 million in 2004 to NOK 600 million in 2010, of which the escalation under the aegis of NANOMAT is from NOK 150 million in 2007 to NOK 250 million in 2010.

The working party finds the recommendations in the Foresight study **realistic and essential**. An overall framework for national investment in N&N through the Research Council of Norway of NOK 140 million in 2007 is thus proposed, steadily increasing in a development phase to NOK 250 million from and including 2011 (to be inflation-adjusted). It should be clearly signalled that the investment is long-term, with a duration of at least ten years from 2007. It seems very probable that the programme ought to be continued also after that time, with undiminished or increasing vigour.

The figures in the table are broken down by areas and measures by the best-estimate method. The exact dimensioning should be undertaken by the Research Council of Norway on the basis of strategic decisions, quality assessments etc. The figures in the table reflect prioritisations undertaken in the strategy work, and indicate the desired levels for the different instrumentalities.

Suggested budget for nanoS&T				
MNOK/year	No growth	2007	2011	2016
Energy	6	17	48	57
ICT	4	14	40	48
Bio-nanoS&T	3	9	25	30
Sea/food	0	2	5	6
Areas of competence	8	28	62	69
Availability	10	20	25	30
Investments	0	50	45	40
Sum	31	140	250	280

Suggested budget for nanoS&T. Numbers for 2007-2011 include earmarked grants for nanoS&T outside the New nano program (relevant for the thematic areas in the upper four rows) - this will not be possible in a no growth-scenario. Activities financed by "New nano program" outside the nanoS&T field (appr. 50 MNOK/year) are not included in the table. Funding for availability should be used by the national centres for infrastructure. Investments include funding for renewal and purchase of new scientific equipment for nanS&T (particularly tool platforms.)

The investment requirement for N&N tools is extremely high, despite the fact that the research institutions have undertaken considerable prioritisations vis-à-vis N&N. This applies to new, dedicated equipment, capacity development to meet national need and after each renewal. The working party proposes that NOK 50 million a year be allocated in the development phase, falling to NOK 40 million a year in 2016. The depreciation period for some of the equipment is short, which necessitates considerable funds for renewal.

If we are to grant funds that ensure the researchers access to advanced equipment and services at the national infrastructure centres and the tool platforms, the measures must be organised and coordinated. It is here assumed that the costs of general operation of the infrastructure centres be covered through other support measures, either from the Research Council of Norway or separate contributions.

The working party is aware of processes to clarify **operational support** to the heaviest laboratories for their availability. In this budget a certain escalation is proposed, from NOK 20 to 30 million a year, partly because of increased investments that have already been made, partly increased demand from research communities and industry. The figure must be revised if the number of national centres/platforms is increased.

It is proposed to increase the share of project funds (the total of thematic priority areas and expertise areas) from approximately 50% in 2007 to approximately 75% in 2016 in line with the escalation. The distribution between the thematic priority areas in the budget is on the basis of evaluations of how Norway can best succeed, scientifically and innovation-wise. The distribution has been held constant in the budget proposal. There is a need for revisions over time on the basis of evaluations of quality, results and opportunities.

Project funds for thematic priority areas and expertise areas can be classified by type of instrumentality: major projects, "normal" projects and individual finance. It is proposed that the relative distribution in percent be 35/45/20 in 2007, adjusted to 50/35/15 in 2016. This means for example three major projects at NOK 8 million in 2007, and 11 at NOK 10 million in 2016. The share of innovation projects among these is expected to increase successively.

The working party proposes that approximately 70–80% of the funds for N&N be channelled through the New Nano Programme. The other funds earmarked for N&N should be distributed through other instrumentalities of the Research Council of Norway. It is emphasised that the funds earmarked for nanotechnology for thematic projects in the other programmes and instrumentalities must be fresh, so that N&N does not displace prioritised thematic research. There is a need for paramount coordination of N&N for thematic priority areas. It is proposed that the responsibility for this be assigned to the "New Nano Programme" (see page 36).

It is emphasised that the N&N investment must be made with fresh funding, so that research that forms the basis of the investment (functional materials, biotechnology, the basic disciplines, thematic priority areas, etc.) is not weakened.

Even if it lies outside the working party's terms of reference, we would here point out the importance of increasing the general appropriations for **materials research** in line with the Foresight study's recommendations [Research Council of Norway 2005]. This will have a positive effect on N&N and a great number of other areas, particularly the thematic.

As discussed on page 36, it is recommended that the New Nano Programme be given responsibility for parts of the materials field and integration. It is recommended that the Research Council of Norway consider stepping up these fields in connection with the implementation of the N&N programme. The budget for the New Nano Programme will, with the proposed investment in N&N and a continuation of the present-day level of other materials research, increase from approximately NOK 160 million in 2007 to NOK 250 million in 2016.

N&N is currently funded to a great degree via the research institutions' own budgets, to a certain extent this applies to industry as well. It is expected that this funding will continue on at least the present-day level. This involves considerable own contributions to the public N&N programme.

The zero-growth budget has been prepared on the basis of the current budget for NANOMAT. This has no room for funds for the thematic priority areas over and above what is assigned to the New Nano Programme. The opportunity for prioritisation, coordination, expertise and methodology is extremely limited. A certain effect can be achieved by de-prioritisation of funds for Ocean/Food. There will be no room for new investments, which will mean that big investments that have already been made, will be poorly exploited. Available funds are so marginal that it is doubtful whether it will be possible to establish national infrastructure centres. There will be no room for major projects.

Advice to various players

Advice to the Research Council of Norway

The working party has concluded that a focused model (page 22) is the most suitable for programmes in the Research Council of Norway and makes the following recommendations and suggestions:

- *N&N for the thematic priority areas specified in this report, should be strengthened with fresh, earmarked funds for N&N directed towards the existing instrumentalities for these areas.*

- *At the same time, a research council programme for N&N, materials and integration should be created. This programme should also be responsible for coordination of N&N in the Research Council of Norway. It is regarded as most natural that the new programme be an expanded and strengthened version of NANOMAT ("New Nano Programme").*

This will mean tangible changes to NANOMAT.

- *The organisation of, including Board representation in, this programme should be reviewed.*

- *A coordination group for N&N should be established, and be led by New Nano Programme.*

N&N is a new field with a long time perspective.

- *The programme must be long-term and last at least ten years from 2007.*

Prioritised instrumentalities to implement the strategy:

- *Focused and strategic funding of major projects and communities that distinguish themselves by particularly high quality and that are working in basic research, more applied research and innovation simultaneously.*

- *Securing of long-term and predictable funding of procurement, renewal and operation of heavy scientific equipment for N&N and for customised niche laboratories for the thematic priority areas. The operational grants must also be dimensioned so that industrial companies and particularly start-ups can make use of the infrastructure and the laboratories.*

- *Investment in individual-based funding, particularly directed at young researchers (international postdocs with repatriation contributions, recruitment posts, guest researchers, starting packages), in order to secure recruitment and international contacts.*

- *Introduction of new instrumentalities for innovation at the R&D institutions that promote collaboration with existing industry or lead to the establishment of new industry.*

- *Over time, strengthening of the funding of user-managed innovation projects.*

There is a growing need for research management in both the field of N&N and similar fields. Managing major projects or interdisciplinary projects that contain components such as basic research, innovation, collaboration with industry etc., demand a form for management in which there is little expertise at the institutions today.

- *The Research Council of Norway should initiate or further develop offers of training in research management that can be offered to researchers in the field of N&N and other areas with corresponding requirements.*

In order to secure a high quality in the programme, evaluation is important.

- *The implementation of the strategy should be evaluated after three to five years, thereafter concurrently. Such evaluation should be undertaken by an impartial, international committee. The targets for follow-up shall be standardised measures for scientific quality (publications, citations, invited lectures, candidates) and for industrial development and innovation (patents, start-ups, industrial cooperation). The first evaluation should consider to what extent the strategy has gotten off the ground, later on, what has been produced should be evaluated.*

Dissemination of results and dialogue with the population is vital to the creation of support for the programme and ensuring a sound development of the field.

- *The Research Council of Norway should create a national strategy for dissemination of N&N and similar disciplines.*

It will be expedient to work more intensively on the innovation aspect.

- *The national strategy for N&N should therefore be followed up with a separate innovation plan for the thematic priority areas, in which leading national companies should be invited to help formulate the plans.*

Advice to the university, college and institute sector

The importance of N&N is expected to increase in the coming years, and will affect the development of disciplines and interdisciplinary technologies. The working party has the following recommendations and suggestions:

- *Take steps at this early stage in order to be able to exploit the expected development in the field of N&N so as positively to support new knowledge and new opportunities in disciplines, technologies and applied research.*

- *N&N represents a new developmental stage of interdisciplinary research. This offers new opportunities, but at the same time demands restructuring and the ability to develop interfaces between traditional disciplines and technologies. This demands awareness and facilitation.*

- *International competitiveness in N&N, both scientifically and as regards innovation, demands a very high professional quality. It is recommended that we create favourable conditions for the development of cutting-edge scientific communities based on advantages at the institutions, plus national network-building.*

Thoroughly adequate operation, maintenance and renewal of the big experimental installations and heavy equipment are crucial to the positive development of N&N. The investments are often so expensive that coordination of N&N infrastructure becomes necessary.

- *The institutions should take responsibility for certain parts of the heavy infrastructure for N&N. The division of responsibility for operation of, maintenance of, access to and renewal of such installations must be clarified between the institutions and the Research Council of Norway.*

If we are to secure future expertise, it is essential to strengthen the educational facilities in N&N. It is also essential to find measures that contribute to securing recruitment to master's, Ph.D. and postdoc levels.

- *The biggest educational institutions should develop and refine study programmes in N&N. It should be considered whether gains can be achieved through national coordination. Active involvement in the EU's master programmes should be evaluated as a new avenue of recruitment for Ph.D. students.*

Activities in the ethical, legal and societal aspects (ELSA) of N&N, including health, the environment and safety, should be seen in connection with other technology areas such as ICT, biotechnology and cognitive research.

- *Activities in ELSA should be established, in part integrated into the rest of the activities. Collaboration with groups doing research in these topics in other technology areas should be strengthened.*

Advice to the Ministries

In 2005 the Research Council of Norway's overall programme in new materials and N&N came to approximately NOK 140 million, of which NANOMAT managed NOK 65 million. Of this again, the share of N&N was NOK 30–50 million, of which NOK 20–35 million via NANOMAT. The Foresight project "Advanced Materials Norway 2020" has made visible how new materials and N&N can trigger new science, progress in a number of societal technologies and thereby innovation. This being so, a drastic increase in the framework for such research is recommended. These recommendations are entirely in line with the central role now played by new materials and N&N in the EU's research programmes.

In order to exploit future progress consequent on N&N and its interdisciplinary penetration of disciplines and other technologies, the working party recommends:

- *An overall financial framework for the investment in the field of N&N of NOK 140 million a year from 2007, steadily increasing to NOK 250 million a year in 2011 and NOK 280 million a year in 2016. The funds for scientific activities in the* *basic subjects outside the N&N area itself, such as chemistry and physics, support the field, and must be maintained on at least the present-day level.*

N&N supports the thematic priorities of the White Paper on Research, basic research and innovation. N&N has both a basic research dimension and a commercial dimension. If Norway is to succeed in fierce international competition, long-term thinking, focusing and coordination are required. Coverage and safeguarding of both the fundamental and the industrial dimension demands coordination between different Ministries.

- *It is recommended that the Ministry of Education and Research establish and lead an interdepartmental group working to secure the long-term appropriations basis for N&N in accordance with current plans. N&N has a broad field of applications, and it is recommended that the sector Ministries take responsibility for relevant thematic priority areas, basic research and innovation. The hydrogen platform may be a model for such coordination.*

N&N can become an important tool for new Norwegian wealth creation. Such research depends on advanced laboratories, heavy instrumentation and advanced methodological expertise. If we are to succeed, resources must be allocated in accordance with an integrated, ambitious plan.

- *An interdepartmentally-appointed group should proffer advice to the Research Council of Norway, universities and research institutions regarding allocations and resources so as to create the best possible synergy effects. This group should on an annual basis collect results and reports related to N&N from these players.*

- *Alternatively, the establishment of a national platform for N&N should be considered, capable of discharging these functions and at the same time proffering advice to the Research Council of Norway, decision-makers, research institutions, the public administration and industry. The secretarial duties for such a group/platform should be assigned to the Research Council.*

Recruitment of new students and personnel at all levels (bachelor, master, Ph.D., postdoc, researcher) is already a limiting factor in key science subjects. N&N may have a recruitment effect provided that the programme is substantial, successful and well-profiled. An adequate recruitment basis must, however, be created now, so that these gains may be achieved subsequently.

- *A national recruitment strategy for the science subjects should be initiated, focusing on master's and doctoral degrees.*

- *Mechanisms for international recruitment should be created, so that development of Norwegian N&N can occur at the recommended tempo and with the recommended scientific and technological profile.*

- *We should facilitate research posts that help to demonstrate tenure tracks and thereby increase recruitment.*

If we are to grasp the industrial opportunities inherent in N&N, it is extremely important that there exists both knowledge of the industrial potential and operational tools for the implementation. These consist inter alia of the innovation system, seed capital and cross-boundary projects between academia and industry.

- *The Ministries are advised, in consultation with other players, to see how the operational tools can be used for optimum addressing of the commercial potential of N&N. The interdepartmentally appointed group mentioned above may be assigned such a mission.*

Advice to industry

Investment in N&N has a long-term character. New technology, components and materials of considerable commercial and industrial interest will successively follow from developments in N&N, and will be related to a number of societal technologies.

N&N is still in an early phase, and is thereby strongly oriented towards fundamentals and technology. This means inter alia a focus on methods for production and characterisation of N&N products – but this, too, offers commercial opportunities.

Increased investment in nanostructured materials, surfaces and particles at the nanometre scale can yield several commercial products with new or highly improved properties. Technology on the basis of processes and devices (including catalysts, sensors, microsystems and measuring systems) will in time become commercially interesting. Industries operating within these fields can achieve a competitive edge, provided that we can at an early date stipulate when new products, processes, techniques etc. exploiting N&N are ripe for commercialisation. In the same way, the infant industry focussing on bioN&N may in the long term experience rapid growth, supplying products of relevance to the health sector (implants, biosensors, nanodrugs etc.).

The level of activity for various industries will vary, from monitoring to leading roles in the development. A national focus on N&N will give industry real opportunities to follow and participate in the development of the field. Particular attention should be paid to allowing industry to gain access to the investment and operations-heavy infrastructure at scientific institutions. Broad research projects aim at generation of expertise and products of direct relevance to a number of technology areas, which offers great commercial opportunities. In the first phase, industry will have great opportunities to affect the investments made in scientific equipment and infrastructure. The opportunity to participate in projects will be good; particularly through the proposed major projects, which shall make room for both basic research and industrial cooperation.

- *The companies are recommended to take an active attitude towards the owners of the experimental facilities (the infrastructure) and thereby endeavour to exploit their expertise and methodology to strengthen and further develop their own products.*

- *Industrial and commercial players are advised to play an active role vis-à-vis the scientific research communities and participate in their research projects (particularly major projects), so as thereby to be in a position to assess technological maturity and commercial opportunities.*

- *The companies are recommended themselves to initiate user-managed innovation projects within their most important strategic technology areas. They should endeavour to collaborate with Norwegian R&D communities.*

- *In return for industry being granted access to the national infrastructure for N&N, industry should participate with investments and expertise in the construction phase.*

Glossary

basic disciplines, the fundamental scientific disciplines of physics, chemistry, biology etc.
biocompatible, able to interface with biological tissue
biomimetic, imitating or resembling natural methods or systems
bioN&N, nanoscience and nanotechnology on the basis of or oriented towards biology and medicine
BIA, User-Managed Innovation Arena, a programme of the Research Council of Norway
BIP, user-managed innovation projects, an application type of the Research Council of Norway
COE, Centre of Expertise, a programme for support to industrial milieus in order to promote regional innovation and commercialisation, developed by SIVA (Company for Industrial Growth), the Research Council of Norway and Innovation Norway
COMPLEX, a Norwegian collaborative project focused on complex systems and soft materials, www.complexphysics.org
catalysis, stimulation or acceleration of chemical reactions, generally with greater yield of the desired product and with the use of less energy
characterisation, observation of materials, processes and phenomena with dedicated equipment, for example with the aid of microscopy, diffraction, spectroscopy etc.
devices, components in microelectronics, circuits and different systems, for example sensors and actuators
ELSA, Ethical, Legal and Societal Aspects, including health, the environment and safety
expertise area, part of N&N of relevance for many thematic priority areas
fluidics, here**:** nanofluidics, dealing with fluids with changed properties due to added nanoparticles or small dimensions in the environment around the fluid
FP, framework programme
FUGE, functional genome research, a programme of the Research Council of Norway
FUNMAT, Norwegian strategic cooperation and national focus on functional materials, www.funmat.no
genome, the total genetic material of a species
genomics, the study of an organism's genome
ICT, information and communication technology
infrastructure, buildings, installations, experimental equipment and expertise that all together constitutes an integrated point of departure for advanced experiments
KMB, an expertise project with user participation, an instrumentality of the Research Council of Norway
knowledge-driven, motivated by curiosity, used of research initiated by researchers
manipulation, handling of materials and structures at the nanometre scale
mesoscopic, concerning phenomena in the range between the atomic (quantum-physics) and the macroscopic (classical-physics) worlds
modelling, describing and predicting materials, processes and phenomena with the aid of calculations performed on (very fast) computers
N&N, nanoscience and nanotechnology
nano-, prefix, a billionth (= the American billion, a thousand million)
NANOMAT, Nanotechnology and New Materials, program in the Research Council of Norway, www.forskningsradet.no/nanomat
nanometre, a billionth of a metre, a millionth of a millimetre
nanoscience, measuring, describing, modelling and systematically manipulating and controlling nanostructures and dynamic processes occurring at the nanoscale
nanotechnology, exploitation of materials, structures, components and systems on the basis of nanoscience
needs-driven, motivated by applications, used of research initiated by industry or society
nm, nanometre
R&D, research and development
SFF, Centre for Excellent Research, an instrumentality of the Research Council of Norway
SFI, Centre for Research-Driven Innovation, an instrumentality of the Research Council of Norway
SMB, small and medium businesses

References

Altmann, Jürgen, Nanotechnology and Preventive Arms Control, 2005. Deutsche Stiftung Friedensforschung, www.bundesstiftung-friedensforschung.de

Cientifica, Nanotubes for the Composite Market, 2005.

CORDIS Thematic Supplement, Exploring the nano-world, Issue 22, March 2006. cordis.europa.eu

COST Strategic Group on Nanoscience and Nanotechnology, Strategy of COST Interests in the Multidisciplinary Field of Nanosciences and Nanotechnologies within the European Research Area, 2005.

Davies, J. Clarence, Managing the effects of nanotechnology, 2006. A Woodrow Wilson International Center for Scholars Report, www.wilsoncenter.org/nano

ETC Group, A tiny primer on nano-scale technologies and "the little bang theory", 2005. www.etcgroup.org

European Commission, Nanotechnology, Innovation for tomorrow's world, 2004. www.cordis.lu/nanotechnology

European Commission, Towards a European strategy for nanotechnology, 2004(b).

European Commission, Proposal for a decision of the European parliament and of the council concerning the seventh framework programme of the European Community for research, technological development and demonstration activities (2007 to 2013), 2005.

European Commission, Nanosciences and nanotechnologies: An action plan for Europe 2005–2009, 2005(b).

European Commission, European Technology Platform on NanoMedicine, Nanotechnology for Health, 2005(c). www.cordis.lu/nanotechnology/nanomedicine.htm

European Commission, Some Figures about Nanotechnology R&D in Europe and Beyond, 2005(d). cordis.europa.eu.int/nanotechnology

European Commission, Looking forward to FP7, Industrial Research Sept. 2005(e). www.europa.eu.int

FUNMAT, Et manifest om Nanoteknologi (A manifesto for Nanotechnology), 2005. www.funmat.no

FUNMAT, Funksjonelle Materialer: Veien mot 2020 (Functional Materials: The Road to 2020), 2006. http://www.funmat.no

Irish Council for Science, Technology & Innovation, Statement on Nanotechnology, 2004. www.forfas.ie/icsti

The Institute of Nanotechnology, Road Maps for Nanotechnology in Energy, 2005. www.nanoroadmap.it

Intel, www.intel.com/technology/silicon/nanotechnology.htm 2006.

Japanese Council for Science and Technology, Report on Mid- and Long-term Research and Development Strategies for Nanotechnology/Materials Science Field in Japan, 2005.

Malsch, Ineke (Editor), Benefits, Risks, Ethical, Legal and societal aspects of Nanotechnology, 2005. A Nanoforum report, www.nanoforum.org

Malsch, Ineke, International Societal Potential of Nanotechnology, talk at NanotecForum 22 June 2005(b), Stockholm, Sweden. www.nanoforum.org

Masciangioli, Tina and Zhang, Wei-Xian, Environmental Technologies at the Nanoscale, Environmental Science & Technology, March 1, p 102, 2003.

Morrison, Mark (Editor), Nanotechnology and its Implications for the Health of the EU Citizens, 2003. A Nanoforum report, www.nanoforum.org

Morrison, Mark (Editor), European Nanotechnology Infrastructure and Networks, 2005. A Nanoforum report, www.nanoforum.org

Nanoforum, Nanotechnology in the Nordic Region, An introduction, 2003. www.nanoforum.org

Nanoforum Energy Report, Nanotechnology helps solve the world's energy problems, 2004. www.nanoforum.org

Nanotechproject, 2006. www.nanotechproject.org

NanoVantage, referred to in Nanotech WireNews, May 5, 2005.

National Institute of Science and Technology Policy, The Seventh Technology Foresight, Future Technology in Japan toward the Year 2030, 2001. www.nistep.go.jp

National Nanotechnology Initiative, 2001. www.nano.gov

National Science Foundation, Societal implications of nanoscience and nanotechnology, March 2001.

NISTEP, Future image of nanotechnology -- according to results of the latest foresight program in Japan, NISTEP report No. 94 -99, 2005. www.nistep.go.jp/index-e.html

Research Council of Norway, Avanserte materialer Norge 2020, Sluttrapport fra et foresight-prosjekt (Advanced Materials Norway 2020, Final report from a foresight project), 2005.

Research Council of Norway, Energi 2020+, Sluttrapport fra et foresight-prosjekt (Energy 2020+, Final report from a foresight project), 2005(b).

Research Council of Norway, Havbruk 2020, Grensesprengende – hvis … En foresightanalyse (Aquaculture 2020, Boundary-breaking – if … A foresight analysis) 2005(d).

Research Council of Norway, Det norske forsknings- og innovationssystemet – statistikk og indikatorer (The Norwegian research and innovation system – Statistics and Indicators), 2005(e).

Research Council of Norway, Nanoteknologier og nye materialer: Helse, miljø, etikk og samfunn, Nasjonale forsknings- og kompetansebehov (Nanotechnologies and New Materials: Health, the Environment, Ethics and Society, National Research and Expertise Requirements), 2005(f).

Research Council of Norway, MNT-strategien (The MNT Strategy), 2006.

Research Council of Norway, Avanserte materialer Norge 2020, Vedlegg I: Materialforskning i Norge (Advanced Materials Norway 2020, Appendix I: materials research in Norway), 2006.

All the reports from the Research Council of Norway are available on www.forskningsradet.no.

Roco, M. C, International perspective on government nanotechnology funding in 2005, J. Nanoparticle Res. 7, 707, 2005.

The Royal Society and the Royal Academy of Engineering, Nanoscience and Nanotechnologies: Opportunities and Uncertainties, 2004.

Saxl, Ottilia, Nanotechnology – a Key Technology for the Future of Europe, 2005.

NTNU, Nanotechnology at NTNU, 2003. www.ntnu.no.

Centre for Materials Science and Nanotechnology, the University of Oslo, SMNano, 2006. www.smn.uio.no

Singer, Peter, referred to in BBC News, UK Ed., April 11th, 2005.

SINTEF, Nanotechnology in SINTEF: Overview, Strategy and Recommendations, 2004.

The Soria Moria Declaration, Politisk plattform for en flertallsregjering utgått av Arbeiderpartiet, Sosialistisk Venstreparti og Senterpartiet (Political Platform for a Majority Government based on the Labour Party, the Socialist Left and the Centre Party), 2005.

Swedish Foundation for Strategic Research, Research Programme for Microelectronics, 2000.

Swedish Foundation for Strategic Research, Research Programme for Materials Science, 2001.

Swedish Nano Network, Strategidokument för Svenska Nanonätverket (Strategy document for a Swedish Nano Network), 2001.

The University of Bergen, “Towards nanotechnology”, A strategy for nanoscience at the University of Bergen 2005-2010, 2004. www.nano.uib.no

The University of Oslo, Nanotechnology at the University of Oslo, 2004.

The University of Oslo, Strategiplan nanoteknologi 2005–2010 (Strategy plan for nanotechnology 2005–2010), 2005. www.uio.no

US National Science and Technology Council, National Nanotechnology Initiative, Strategic Plan, 2004. www.ostp.gov/nstc/index.html.

US National Science and Technology Council, The National Nanotechnology Initiative, Supplement to the President’s 2006 Budget, 2005. www.ostp.gov/nstc/index.html

US President’s council of advisors on science and technology, The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, 2005. www.ostp.gov

(Norwegian) Ministry of Education and Research, Report to the Storting No. 20, Vilje til forskning (The Will to Research), 2005.

Van Rheenen, Arthur D., Nanoteknologi – En innføring (Nanotechnology – an Introduction), 2005. FFI report, www.ffi.no

VDI/VDE – Innovation und Technik GmbH, Impact of Nanotechnology in Health and Medical Systems, 2005. www.nanoroadmap.it

(Danish) Ministry of Science, Teknologisk fremsyn om dansk nanovidenskab og nanoteknologi, Handlingsplan (Technological Foresight in Danish Nanoscience and Nanotechnology, Action Plan), 2004. www.technologicalfremsyn.dk

Willems & van den Wildenberg (W&W), Materials roadmaps, 2005. www.nanoroadmap.it

Appendix 1.
Norwegian expertise in N&N

In connection with the Foresight study "Advanced materials Norway 2020" the Research Council of Norway undertook a fundamental analysis of materials research in Norway, in which N&N was included as an important element [Research Council of Norway: "Advanced Materials Norway 2020, Appendix I: Materials Research in Norway", May, 2006]. This provides several details about N&N research in Norway. To give a summarising example, 550 scientists are currently researching materials technology and the materials-related component of N&N. Exact figures for the overall number of researchers in N&N are difficult to estimate.

The following table shows the N&N research and development activity at the various institutions. The table has been compiled on the basis of information from the institutions' own web-pages, the Research Council of Norway's open home-pages and in certain cases direct contact with the institution. It is not intended to be exhaustive, but has been included in order to show the possible breadth of a grand investment in N&N in Norway. Institutions with activities are listed in alphabetical order (of their names in the original language).

Who	Description
Norwegian Defence Research Institute (FFI)	FFI's primary mission is to advise the military and security-policy leadership of the Norwegian Armed Forces about the consequences of scientific and technological developments for defence and security policy, and to help ensure that such developments are exploited in the national interest. The Institute also conducts its own research activities in N&N, primarily in sensors, optical systems and in structural materials.
Vestfold University College (HVE)	The Institute for Microsystem Technology (IMST) at HVE trains engineers in micro and nanotechnology (MNT) at bachelor's and master's level Training at doctorate level takes place in collaboration with the University of Oslo. Research at HVE is oriented towards innovation. The programme includes micro and nanostructuring of silicon, surface treatment and thin film technologies, use of biocompatible materials for encapsulation of microsystems and methods for building and testing of three-dimensional heterogeneous microsystems. Applications include measurement of pressure, ultrasound and movement, electro-optical microcomponents, micro-energy sources for harvesting and storage of energy and microsystems for biotechnology and medicine. HVE invests in laboratories with combined technology for building, testing and characterisation. HVE leads the "Norwegian Centre of Expertise – Microsystems" on behalf of 13 companies in ICT and microsystems. Exploitation of nanotechnology for ICT/microsystems is important for this programme.

Institute for Energy Technology (IFE)	IFE has nano-relevant activities at the following departments: The Department of Physics, materials and corrosion technology, nuclear safety and reliability, energy systems and metallurgy. IFE has a strategy directed towards N&N in preparation, and has defined "basic research in physics on the basis of the Jeep II reactor at Kjeller" as one of its four main tasks – this is mostly fundamental materials science. The JEEP II research reactor is one of the extremely few neutron sources for materials research in Europe. The research covers the following areas in N&N: • nanostructured materials • complex and soft materials, fluids • self-organisation of nanoparticles • target-seeking nanomaterials as tracers and in corrosion inhibition and surface modification.
Geological Survey of Norway (NGU)	NGU conducts R&D into naturally-occurring nanostructured materials, including the application of such materials.
The Norwegian University of Science and Technology (NTNU)	N&N at the NTNU covers theoretical and experimental activity plus fundamental and applied research. The Faculty of Natural Science and Technology is the most active, but there is also activity at the Faculty for Information Technology, Mathematics and Electrical Engineering, the Faculty of Medicine, the Faculty for Engineering Science and Technology plus The Faculty of Arts (ethics). The mission of the NTNU NanoLab is to create an interdisciplinary research community in N&N and focuses on four areas: • nanoelectronics, nanophotonics and nanomagnetism • nanostructured materials • bionanotechnology • nanotechnology for energy and the environment NTNU NanoLab is establishing state-of-the-art laboratory infrastructure including clean rooms for N&N. This includes synthesis with the aid of chemical, physical and biological methods plus advanced characterisation. N&N is also important in the NTNU's thematic priority areas Materials, Medical Technology, Information and Communication Technology plus Energy and Petroleum – resources and the environment.
The Paper and Fibre Institute (PFI)	PFI conducts extensive activities on nanostructured biomaterials. These materials concepts are developed and applied in various products. Of promising applications we might mention composite technology, flow modification, emulsion stabilisation, films, packaging and coating. In addition to these, several other interesting future applications are ready to be researched. This strategic programme in proceeding in close collaboration with industrial partners, STFI-Packforsk, SINTEF, Matforsk and NTNU.

SINTEF	SINTEF has its main activities in N&N in two entities: SINTEF Materials and chemistry and SINTEF ICT. SINTEF envisages markets both on the product side, in R&D and technology dissemination. Important links with NTNU via NTNU NanoLab and with the UiO via SMN MiNaLab mean that SINTEF is also an important player in fundamental research and has interventions in important infrastructure. SINTEF's activities in the field of N&N are diverse and include both fundamental and particularly applied research. SINTEF's strategy report on N&N points to some key areas: • nanoparticles with particular focus on controlled liberation of components and coating • new, smart materials, with particular focus on catalysis • sensors on the basis of micro/nanosystem technology (including biosensors) SINTEF also encourages the development of nanobio-related expertise, and has here commenced a good number of number of activities. SINTEF also emphasises HSE and ethics, both as independent areas and as an integrated component of nanotechnology projects and activities.
The Norwegian University of Life Sciences (UMB)	The Department of Plant and Environmental Sciences at UMB has expertise in particle detection, co-toxicology and ethical evaluations of new technology.
The University of Bergen	The activity is currently organised as a multi-disciplinary set of research projects under the umbrella of NanoUiB [UiB 2004]. The following entities are represented in the collaboration: the Department of Physics and Technology, the Department of Chemistry, the Department of Mathematics, the Department of Computational Science (BCCS), the Department of Molecular Biology, the Department of Bio-Medicine, the Department of Biology and the Department of General Medicine and Clinical Odontology. In 2005 the University of Bergen adopted a strategy for N&N on the basis of a report of October 2004 [UiB 2004]. There it was proposed to establish N&N as a long-term focus area at UiB. The period 2005-2010 was to be used to build up this activity, and the strategy recommends an internal funding level of in all NOK 100 million in this period. Projects fall into four areas: • bionanotechnology • nanostructured functional materials • fundamental/modelling-based nanoscience • nanoethics

The University of Oslo, including the Radiumhospitalet (Comprehensive Cancer Centre) and University Hospital (Rikshospitalet) (UiO)	The bulk of the activities in N&N at UiO is gathered together in the Centre for Materials Science and Nanotechnology (SMN). An important part of the activity proceeds at the Micro-Nano-Laboratory (MiNaLab), which was built in collaboration with SINTEF and was completed in 2004. SMN published its strategy for N&N, "SMNano" in January 2006 [SMN 2006]. This was based on the strategy for the central programme FUNMAT@UiO [UiO 2005], whose scientific details are broadly described in a report from 2004 [UiO 2004]. Nanotechnology at UiO shall support activities in fundamental questions, materials and components related to: • energy technology • environmental and process technology (including oil and gas) • ICT (including microsystems) • biomaterials and medical technology • ethics Specific to SMN, five focus areas are described: • energy, environment and process: Catalysis in nanovolumes and on nanoparticles • nanostructured materials: Design and production of nanostructures • generic expertise: Functional surfaces • generic expertise: Mesoscopic physics • applications: Nanocomponents and nano-sensors
The University of Stavanger (UiS)	The University of Stavanger conducts research into nanotechnology inter alia via collaborative projects with FFI/UiO and Agder University College/UiO. The projects are related to characterisation with transmission electron microscopy.
The University of Tromsø (UiT)	At the University of Tromsø there are relevant activities in the development and application of theoretical models, self-organising processes for production of (bio)molecules, integrated optics for micro-sensors, drug transport and drug delivery.
The University Graduate Centre at Kjeller (UNIK)	UNIK is engaged in R&D in optics, in which N&N is utilised in order to create the optical sensors of the future (better and cheaper). The activity is conducted in collaboration inter alia with UiO.

In addition there are activities in progress that in the long term may create fertile soil for investment in nanotechnology and new materials at the following institutions:

- Agder University College (HiA)
- Narvik University College (HiN)
- Sør-Trøndelag University College (HiST)
- Telemark University College (HiT)
- NORUT Technology

Appendix 2. Anchorage of the strategy

Great emphasis has been laid on openness and contributions from the Norwegian research communities under preparation of this strategy. At an early stage in the process, a page was constructed in NANOMAT's home pages (www.forskningsradet.no/nanomat) with background information and ongoing briefing about the status of the process. At the same time, an electronic mailbox for input regarding the strategy, and almost 200 suggestions have been received. Minutes of meetings and several temporary versions of the reports have been available through the web-page, and the working party has received input via two consultation rounds. On 9 June 2006 an open consultation meeting was also arranged, with about 40 participants.

Appendix 3.
Reply to the terms of reference

The advice requested in the terms of reference is here reproduced with appurtenant comments on how this has been followed up in the report.

1. Disciplines/research communities in which Norway, in the light of national needs and capabilities, should be among the international leaders. *There has been no room for a comprehensive evaluation of the Norwegian milieus in this work, so that specific milieus have not been indicated. Important disciplines for Norway have been identified, and to a certain extent prioritised, on page 24. Within these areas it is recommended that funds be allocated on the basis of competition and international assessments.*

2. Identification and prioritisation of new focus areas. *The thematic priority areas and generic expertise areas presented in the chapter "Prioritised focus areas" on page 24, comprise the prioritised areas in this strategy.*

3. Measures to improve the recruitment situation in various disciplines and sub-areas, including the need for additional doctoral and postdoc fellowships, plus other measures that will address the need for professional expertise in the institute sector and in industry, and in the professional disciplines. *A package of instrumentalities to improve recruitment is proposed. This is discussed on page 22, and recommended measures are listed on pages 33 and 39.*

4. Measures for further development of national coordination and division of labour between disciplines and research communities in order to achieve utilisation of resources nationally. National coordination of laboratories and equipment should be emphasised. *Coordination and division of labour is discussed on page 20, and recommendations are to be found on page 32.*

5. Measures for enhanced mobility of Norwegian researchers, both nationally and internationally, and measures for enhanced internationalisation. *Recommendations for this are to be found on pages 33 and 39.*

6. Measures for increased industrial growth in relevant industrial sectors in Norway, on the basis of enhanced cooperation between the university, college and institute sector and industry. *Recommended measures for innovation and industrial development are to be found on pages 32 and 39.*

7. Research management and relevant measures for further development and improvement of the current situation. *Research management is discussed on page 21, and recommendations are made on page 35.*

The Research Council of Norway
P.O. Box 2700 St. Hanshaugen
0131 OSLO
Telephone: 22 03 70 00
Fax: 22 03 70 01

bibliotek@forskningsradet.no
www.forskningsradet.no

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