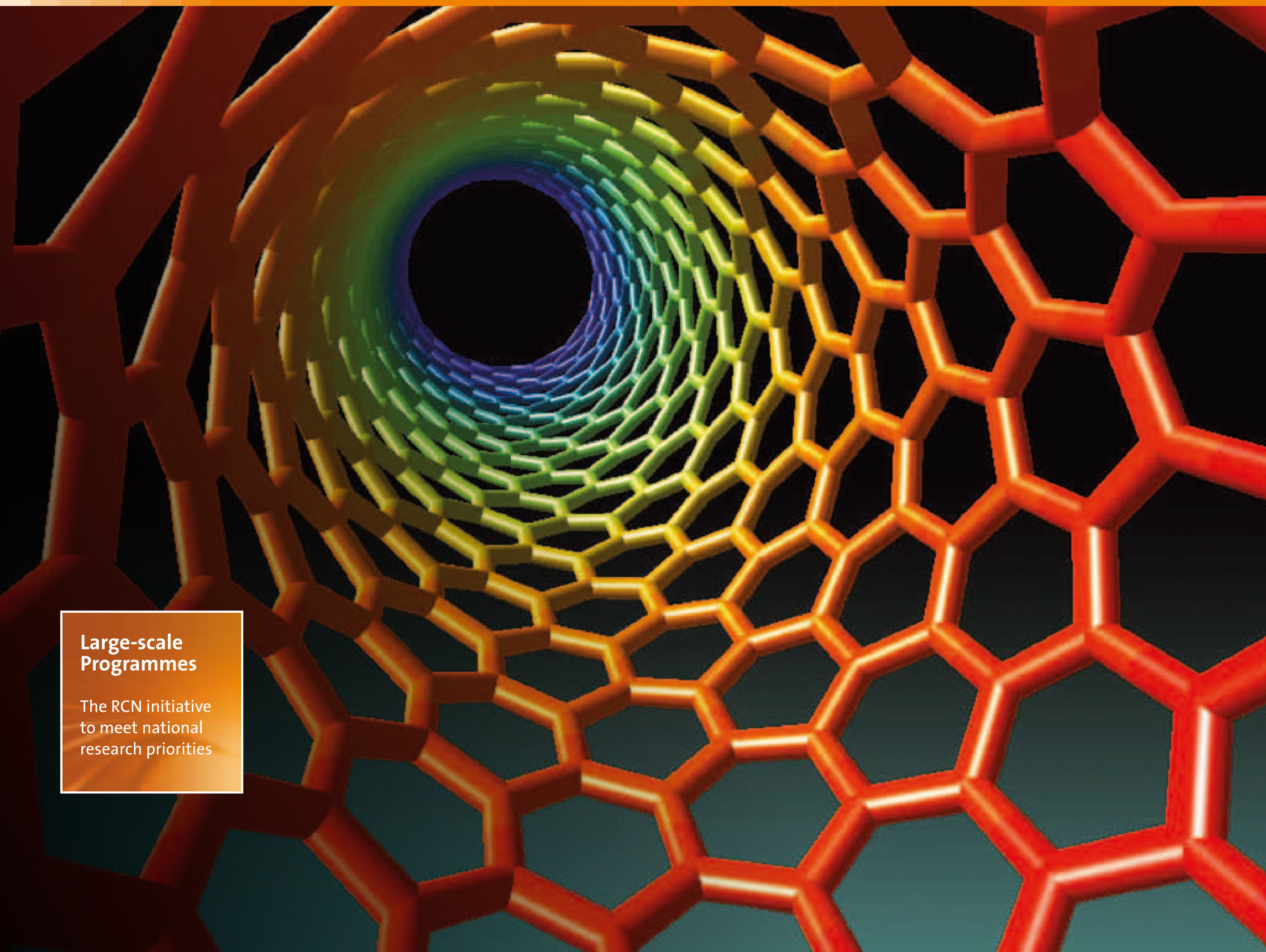
The Research Council of Norway

Tiny technology – big progress

A summing up of 10 years of activity

Large-scale Programme

Nanotechnology and New Materials (NANOMAT)



About the programme
Nanotechnology and New Materials (NANOMAT) (2002-2011)

The NANOMAT programme has boosted national knowledge development in the national priority area of nanotechnology and new materials by providing funding for basic and long-term research and technology development.
The programme has also encouraged research and technology development activities in trade and industry by allocating funding to industry-oriented projects, thereby laying the foundation for tomorrow's knowledge-based industry.

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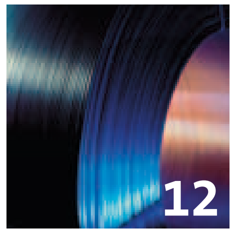


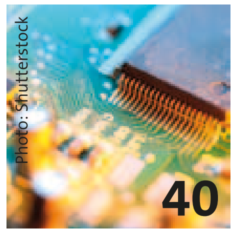


Photo: Sverre C. Jarild

Excellent basis for continued activities

Nanotechnology involves the application of knowledge and phenomena at the nanoscale. Nano- and materials technology may help to solve challenges facing the global society by increasing access to environment-friendly energy, technology to improve health, and technology for tackling environmental problems and promoting the sustainable use of natural resources.

The Research Council of Norway launched the programme Nanotechnology and New Materials (NANOMAT) in 2002. During its 10 years of existence, the programme has helped to build an excellent national knowledge base in a field that was relatively new in Norway. Fruitful forms of cooperation and effective task-sharing between research groups were developed at the national level, and Norway now has dynamic research groups in selected areas, particularly in solid-state physics and chemistry.

This report provides a broad overview of the results of a portfolio comprising nearly 150 projects. The basic knowledge generated has given us a new understanding of nature. The new materials developed have been used to create technology for more effective solar cells and for harvesting energy from renewable sources. Materials with new functional properties have provided the basis for future ICT solutions for information management and flow. In terms of health, innovative strides have been made in targeted drug delivery and improved tissue engineering and implant construction. The following pages introduce readers to research projects within these and other areas under the NANOMAT programme.

An external evaluation of the NANOMAT programme concluded that the programme has achieved its objectives. Funding has been allocated to research projects in national priority areas, and the quality and capacity of research in the field has improved considerably since the programme was launched. Norwegian trade and industry has also become more actively involved, particularly during the latter part of the programme period.

The Research Council has recently established the Programme on Nanotechnology, Nanoscience, Microtechnology and Advanced Materials (NANO2021) to continue the efforts of the NANOMAT programme. The NANO2021 programme is designed to further develop the field by cultivating outstanding research, but it will also attach even greater importance to strengthening cooperation between the research community and trade and industry. The new programme will have a clear profile in order to develop knowledge and promote value creation in the areas of energy and the environment, health, and the sustainable use of natural resources. At the same time, the programme will seek to ensure that technology is developed in a socially responsible manner and to the benefit of both the individual and society at large.

Photo: Sverre C. Jarild

Arvid Hallén
Director General

About the programme

The Large-scale Programme Nanotechnology and New Materials (NANOMAT) was conducted to fulfil national research needs. In the course of its 10 years of existence, the programme has given a significant boost to the quality and capacity of research in a field that was relatively new in Norway.

Background and framework

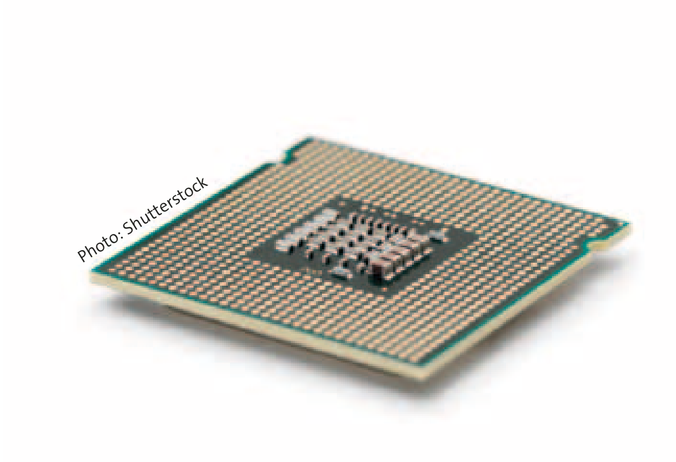
Evaluations of Norwegian physics and chemistry research were conducted in 1998-1999. These concluded that research quality, infrastructure and financial allocations in these disciplines lagged far behind internationally. It was recommended that a new research initiative be established to give priority to research on nanotechnology and new materials.

Launched in 2002, the NANOMAT programme had its roots in the FUNMAT consortium, which was comprised of several nationally-leading research environments in the field of nanotechnology and new materials. The aim of establishing the NANOMAT programme was to bring selected areas of Norwegian nanotechnology and materials research up to an international level of activity.

The 2001 evaluation of the Research Council of Norway recommended the establishment of focused, long-term initiatives in "large thematic areas". The Research Council followed up this recommendation and launched the Large-scale Programme initiative as a key funding instrument for realising national research policy priorities. This initiative was designed to build long-term knowledge in order to encourage innovation and enhance value creation as well as to help find solutions to important challenges facing society. The Large-scale Programmes extended across various sectors and value chains and incorporated a wide variety of actors, providing them with a strategic and dynamic arena for communication and cooperation. The NANOMAT programme was incorporated under the Large-scale Programme initiative in 2004. The programme has served as a key component of the Research Council's activities in the field of nanotechnology and materials, which is a priority technology area identified in the government white paper on research, *Commitment to Research* (2005).

The NANOMAT programme has been the Research Council's targeted initiative in the field of nanotechnology and new materials. The programme has had special responsibility for national coordination of research activities in the field. To this end, the programme has launched and funded a number of nationally-coordinated projects across research institutions in Norway. The programme has typically funded projects in which nanotechnology and/or functional materials form the technological backbone of the project. Projects involving applications based to a greater or lesser extent on nanotechnology and/or functional materials have also received funding under other programmes at the Research Council, particularly the Large-scale Programme Clean Energy for the Future (RENERGI) and the Programme for User-driven Research-based Innovation (BIA). The Large-scale Programme Optimal Management of Petroleum Resources (PETROMAKS), the programme Maximising Value Creation in the Natural Gas Chain (GASSMAKS) and the funding scheme for independent projects (FRIPRO) under the Division for Science have also allocated funding for such projects. The Research Council's overall investment in nanotechnology and new materials research increased from NOK 215 million per year to NOK 310 million per year during the period 2006-2010. During that same period the NANOMAT programme had an annual budget of NOK 80-120 million. Figure 1 shows that the largest investments in 2009 and 2010 were made in the area of functional materials, followed by nanotechnology, nanoscience, micro- and nanoelectronics, and health, safety and environment (HSE).

The Ministry of Education and Research was the NANOMAT programme's most important funder. The Fund for Research and Innovation and the Ministry of Trade and Industry were also key funding sources. Table 1 shows the programme's income per year for the entire programme period. At its conclusion at the end of 2011, the programme had a surplus of well over NOK 2 million.



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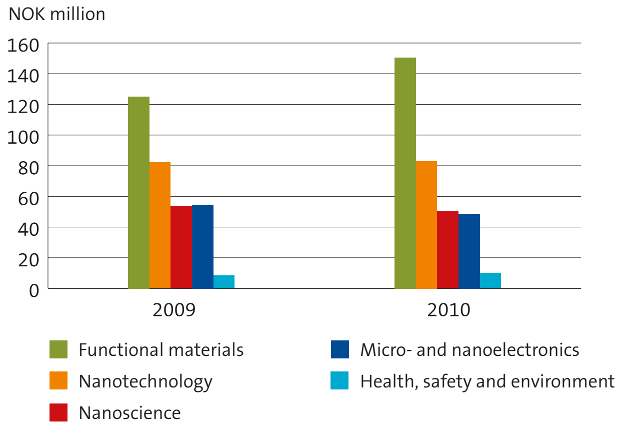
The NANOMAT programme has achieved its objectives – this is the main conclusion of an external evaluation of the programme.

Figure 1. The Research Council's overall investment in 2009 and 2010, by technology area (in NOK million).



Nanoscience >>

Nanoscience is generally defined as the science of understanding processes and phenomena occurring at the nanoscale, synthesising and processing nature's own building blocks (atoms, molecules or macromolecules), and generating knowledge about how control at the nanoscale can be used to develop materials and components with new and unique properties. Nanotechnology is the study and art of applying nanoscience in practice. Nanotechnology is by nature interdisciplinary, encompassing physics, chemistry, biology, molecular biology, medicine, electronics, and information and communications technology (ICT). Functional materials get their unique functional properties from their composition and the way in which they are constructed from the micro- to the macro-level and from the physical and chemical processes and phenomena that occur within them.

Table 1. Income for the NANOMAT programme, by source and by year (in NOK million).

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Ministry of Education & Research		30.0	43.8	31.7	32.6	32.6	32.6	32.7	37.7	37.7
Fund for Research & Innovation	8.5	26.9	26.9	29.9	29.9	20	55.0	25.0	25.0	25.0
Ministry of Trade & Industry			3.8	3.7	13.4	14.4	14.4	32.4	32.4	32.4
Ministry of Petroleum & Energy							16.1			
Orkla AS						10.0				
Per year	8.5	56.9	74.4	65.5	60.9	77.0	118.2	90.1	95.1	95.1
Aggregated	8.5	65.4	139.8	205.3	266.2	343.2	461.4	551.5	646.6	741.7

Objectives and priorities

From the very start, a primary objective of the NANOMAT programme has been to promote Norway as a world leader in selected areas relating to nanoscience, nanotechnology and new materials. The programme was also designed to pave the way for new knowledge-based, research-intensive industry and the sustainable renewal of Norwegian industry. By allocating funding to research projects of high quality and relevance for academia and trade and industry, the programme would generate new knowledge, increased value creation, sustainable solutions and a better understanding of nature. This also entailed responsibility for ensuring that new knowledge and technology are utilised to the benefit of society. The programme therefore gave priority to research on issues relating to health, safety and environment (HSE) and socially responsible technological development.

The NANOMAT programme has addressed important societal challenges. The government white paper on research published in 2009, *Climate for Research,* emphasised the need for the research community to address major challenges facing society. While the main focus of the programme in its initial years was on broad-based competence-building in the field, the research carried out during the latter part of the programme was more industry-oriented, and importance was placed on ensuring the relevance and benefit to society of the research and on creating technological solutions to help to solve pressing societal challenges. This reflected a general international trend in which the "grand challenges" emerged as research priorities. In its Communication from 2011, the European Commission identified advanced materials, photonics, nanotechnology, micro- and nanoelectronics and biotechnology as Key Enabling Technologies (KETs) of major significance for strengthening the EU's industrial and innovation capacity. In terms of key national and global challenges, the NANOMAT programme placed particular focus on forms of renewable energy, new ICT and microsystems solutions, better health, environmental technology, and new solutions within the area of oceans and food (Figure 2).

Results

The NANOMAT programme has provided support for R&D activities along the entire value chain. The programme allocated roughly NOK 700 million in funding to 140 projects. The last of the projects will conclude in 2013. The programme's project portfolio encompasses the entire value chain, from basic competence-building to innovation and commercialisation. Just over NOK 200 million was allocated to 53 projects to reduce the level of risk associated with industry's own R&D activity in the field. This support primarily took the form of funding for *innovation projects for the industrial sector,* but funding was awarded to *pre-projects* and for *commercialisation measures* as well. Trade and industry contributed NOK 200 million of its own resources (Figure 3). The programme also employed *knowledge-building projects for industry* and *large-scale institution-based projects* as key funding instruments to direct the attention of the research community (academia and independent research institutes) to the needs and problems of trade and industry.

The NANOMAT programme has promoted socially responsible technological development. Most societal challenges extend across sectors, institutions, professions and disciplines. Socially responsible technological development therefore entails broad-based involvement on the part of academia, trade and industry, the public administration and interest organisations in all phases of the research processes. Problems, as well as solutions, must be defined in a dialogue between all of these parties. The programme has provided funding to research projects on issues relating to health, safety and environment (HSE) and risk, as well as on ethical, legal and social aspects (ELSA) of the development and application of nanotechnology and new materials. In the final year of the programme, a special effort was made to establish integrated projects involving cooperation between researchers in technology fields and the social sciences.

The NANOMAT programme has supported the priorities and educational programmes of the institutions themselves. In addition to allocating funding for a number of doctoral and post-doctoral fellowships within the framework of the research projects, the programme provided support to establish a national graduate-level researcher school, the Norwegian PhD Network on Nanotechnology for Microsystems. Top-modern infrastructure has been established in Norway in recent years thanks to a concerted national effort, in which the NANOMAT programme has been an active participant. Basic competence-building under the NANOMAT programme also led to the realisation of the Norwegian Research Centre for Solar Cell Technology, which is a Centre for Environment-friendly Energy Research (FME) and the national team for solar cell research in Norway ("Solar United"), as well as a Centre for Research-based Innovation (SFI) for catalysis, Innovative Natural Gas Processes and Products (InGAP). Figure 4 shows the distribution of funding to various institutions. In the higher education sector, the Norwegian University of Science and Technology (NTNU) received the most funding. In the institute sector, the SINTEF Group received the most funding. This diagram presents a somewhat skewed picture, particularly when it comes to large-scale, nationally-coordinated projects, as the project partners are not visible as funding recipients. For example, it appears that the University of Oslo received less funding that it actually did.

The NANOMAT programme has attached importance to communication activities and social dialogue. The NANOMAT programme has attached importance to communication activities and social dialogue. The objective of the programme's communication activities was to enhance knowledge and promote informed debate about developments in the field. Starting in 2008, the social debate on the potential dangers of nanotechnology has been growing. The programme has engaged in wide-ranging social dialogue, organising a number of dialogue meetings between researchers and stakeholders, and actively carrying out communication activities throughout the entire programme period. News briefs and newsletters were published regularly on the NANOMAT webpages, and the programme provided funding for a short film about nanotechnology, energy and the environment. A long-time participant in Norway's National Science Week, the programme gave priority to dissemination activities targeting the general public and children and young people, including popular science lectures and special collaborative measures such as the development of *Nanoskopet,* an interactive nanotechnology mini-lab on the website forskning.no, an issue of *Nysgjerrigper* magazine dedicated to nanotechnology, and the *SciLab* mobile laboratory for schoolchildren in Norway. The programme also provided co-funding for three dissemination projects, in collaboration with the PROREAL programme for raising the profile of mathematics and science.

Figure 2. Distribution of funding, by major societal challenge (in NOK million).

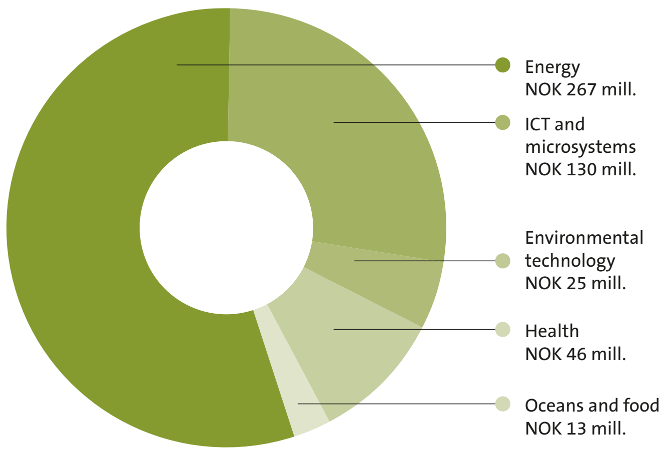


Figure 3. Distribution of funding, by type of support, for the period 2002-2013 (in NOK million). Industry primarily contributed resources to knowledge-building projects and innovation projects.

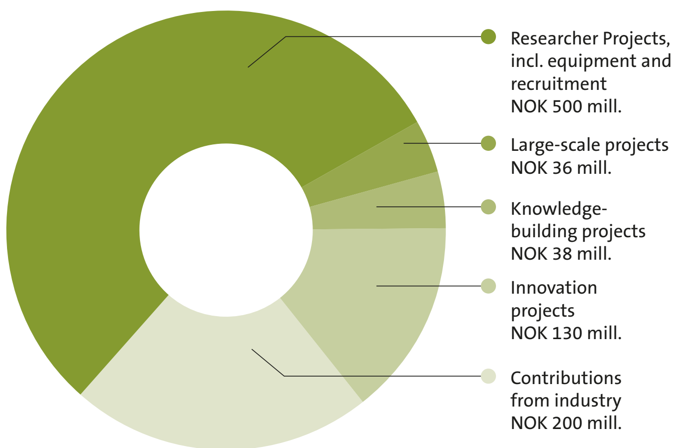
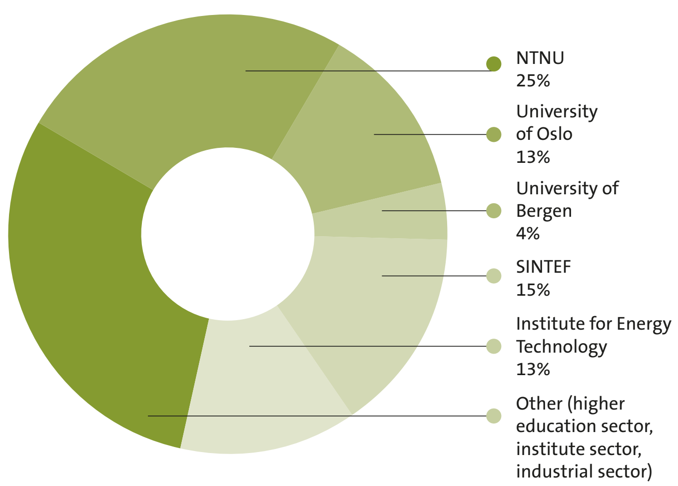


Figure 4. Distribution of funding to national R&D players during the entire programme period (in %).



Results of the NANOMAT programme	Aggregated results (2002-2011)
Publications, peer-reviewed	1121
Published lectures from international meetings	782
Other reports and lectures	1100
Number of patents and patent applications	56
Number of new companies	6
Number of new products and processes	31
Number of new methods, models and prototypes	101

PART 1 / NANOMAT – ABOUT THE PROGRAMME

The NANOMAT programme has achieved excellent results. The fact box on p. 9 presents selected aggregated results from projects in the programme portfolio as at December 2011. These figures have not been finalised. Results are often first fully realised after the contract with the Research Council has expired. Therefore, publications or patents awarded after the conclusion of a project are not included here.

External evaluation of the NANOMAT programme

The NANOMAT programme has achieved its objectives. This is the main conclusion of an external evaluation of the programme conducted by the consulting firms DAMVAD of Denmark and Econ Pöyry of Norway, in cooperation with experts in both the respective technology areas and the evaluation of funding instruments.

The evaluation report concludes that the NANOMAT programme has helped to: >>

- Strengthen the quality and capacity of Norway's nanotechnology research groups;
- Establish a long-term perspective and raise national awareness about a relatively new research field;
- Establish binding cooperation and division of labour between leading research groups;
- Establish nationally-coordinated projects as a pillar of national research in the field;
- Direct the focus of research activities towards solving societal challenges;
- Strengthen and promote the renewal of R&D activity in trade and industry;
- Increase the internationalisation of Norwegian R&D activities;
- Promote socially responsible technological development;
- Enhance general and specialised knowledge about the research field.

Evaluation of quality and publication. Today Norway's R&D community enjoys the fruits of the competence-building carried out under the early years of the NANOMAT programme. The nationally-coordinated projects played a vital role in this context. In 2002 scientific production in the field in Norway was clearly much lower than the international average. The evaluation report points out that the NANOMAT programme helped to boost the publication rate dramatically, even though Norway still produces fewer scientific publications per 1 000 inhabitants than researchers in the other countries included in this analysis (Figure 5). Of the publications issued under the NANOMAT programme, 23% were published in top international journals.

Evaluation of cooperation, task-sharing and national knowledge base. An overall objective of the NANOMAT programme for its entire duration has been to generate knowledge across the dividing lines between research communities and create national arenas for cooperation between the researchers, the public administration and trade and industry, with particular focus on recruitment. A total of over 200 doctoral and post-doctoral degrees were completed with support from the NANOMAT programme. Background figures for the evaluation show that 80% of the project managers within the programme's portfolio agree that the programme to a great or some extent has helped to boost cooperation between Norwegian research environments. Correspondingly, a large proportion of the project managers believe that the programme has helped to strengthen research-based knowledge in Norway (Figure 6).

Evaluation of societal challenges. The evaluation report emphasises that the NANOMAT programme successfully adapted to changing priorities in Norwegian research policy during the programme period. According to the report, the programme managed to boost Norwegian R&D in the field considerably and, over time, to direct the focus of research activities towards solving challenges facing society. In the course of its 10-year duration, the programme evolved from a "basic research programme" to one with a much broader scope, in keeping with the intentions of the Large-scale Programme initiative, under which relevance and benefit to industry and society are key criteria.

Evaluation of industrial development. The NANOMAT programme has successfully encouraged greater industry involvement in R&D, thereby enhancing knowledge and stepping up the level of R&D activity in industry, particularly during the second half of the programme period. Nearly 100 companies participated in projects funded under the NANOMAT programme, and 27% of the programme's projects reported industry participation. The evaluation report points out that the programme was most successful in strengthening the existing knowledge base and renewing R&D activities in established industry. The programme had a far more moderate effect in relation to new, knowledge-based industry. It is interesting to note that the companies themselves highlight their own competence-building and access to the research front as significant results of project participation and that these have been just as important to them as solving a concrete technical problem. According to the evaluation report, industry is calling for more and new arenas for cooperation between companies and research institutions.

Evaluation of the internationalisation of Norwegian research groups. The strategic measures undertaken by the NANOMAT programme to build knowledge through cooperation, task-sharing and concentration of funding and effort boosted the level of national knowledge, so that today Norwegian research groups are conducting internationally competitive research and are attractive partners for research cooperation in selected areas. Fifty-five per cent of the project managers reported the participation of international research groups in their projects. According to the evaluation report, the NANOMAT programme helped to enhance the internationalisation of the projects. The programme helped to lay the foundation for further strengthening Norway's international orientation in the field (Figure 7) and also helped to make Norwegian research groups better equipped to succeed in the competition for funding under EU programmes for research and innovation.

The road ahead

In accordance with the priorities set out in the government white paper on research and based on the extensive knowledge platform that has been developed, the Programme on Nanotechnology, Nanoscience, Microtechnology and Advanced Materials (NANO2021) is being launched as a 10-year, large-scale programme that will run from 2012 to 2021. The NANO2021 programme will cultivate concentrated, integrated research activities to further enhance the expertise, quality and capacity built up by Norway's R&D community in the field of nanotechnology and advanced materials during the past decade, in part under the NANOMAT programme. The development of basic knowledge and innovative solutions will strengthen Norwegian trade and industry and help to resolve wide-ranging societal challenges relating to energy and the environment, natural resources and health. This entails ensuring that new knowledge and technology are utilised to the benefit of society. The new programme will therefore attach greater importance than its predecessor to research on health-related, environmental and social issues relating to the development and application of nanotechnology. The Norwegian Government's new national strategy for nanotechnology (to be launched in 2012) will provide the framework for further targeting of research topics, focus areas and priorities under the programme and for the ultimate design and focus of the work programme.

Figure 5. Relative development in number of publications in the area of nanotechnology for the period 1992-2009 (at left). Number of publications per 1 000 inhabitants in selected countries (at right). Source: DAMVAD.

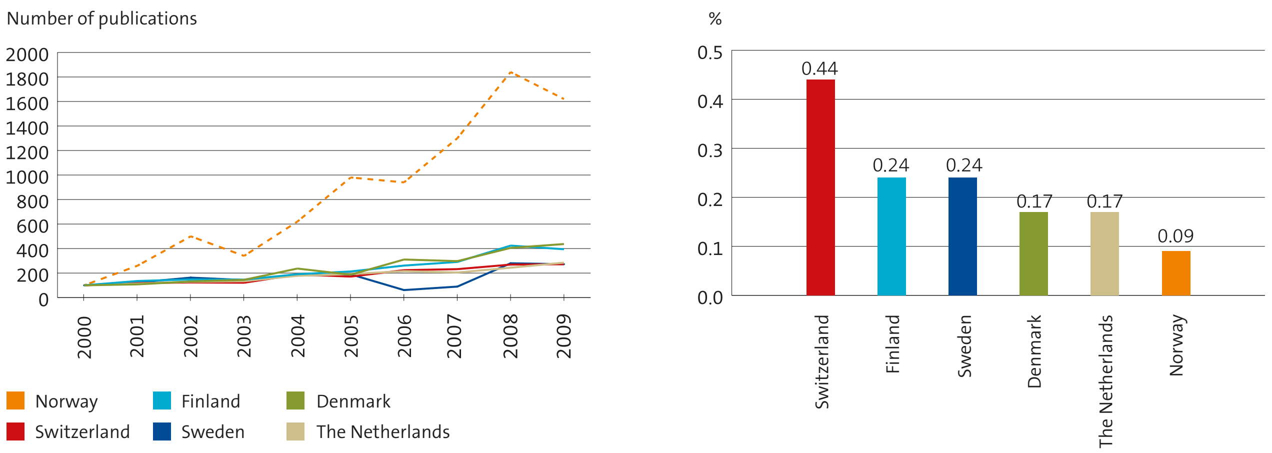


Figure 6. Percentage of project managers who believe that the NANOMAT programme has helped to strengthen research-based knowledge and expertise in materials and nanotechnology in Norway in general. Source: DAMVAD.

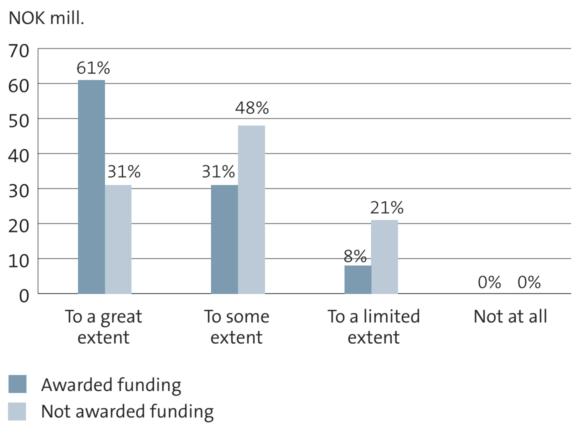
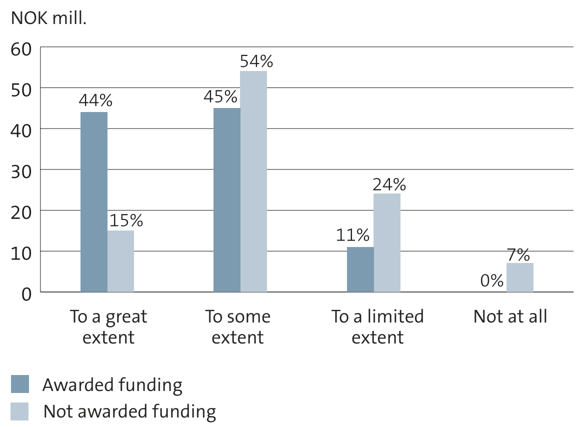


Figure 7. Percentage of project managers who believe that the NANOMAT programme has enabled Norwegian research groups to keep pace with developments at the international research front. Source: DAMVAD.

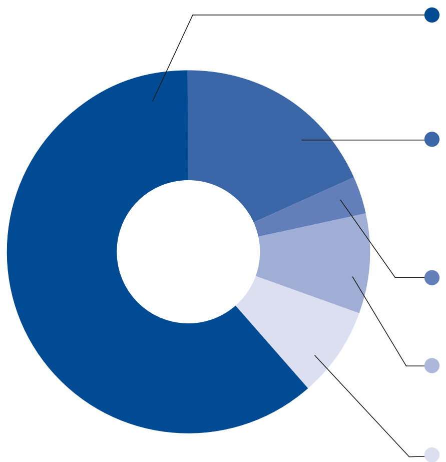


Quality, capacity and expertise

Since its launch in 2002, the NANOMAT programme has focused on building national expertise in what was a relatively new field in Norway, attaching importance to national coordination and task-sharing, infrastructure and recruitment. In its early years, the programme placed greater focus on basic competence-building. In more recent years, focus has been directed towards knowledge and competence-sharing and ensuring the benefit to society of the research. The programme has also given priority to targeted recruitment measures such as a graduate-level researcher school and personal post-doctoral fellowships. Establishing infrastructure has been an important area of focus as well. As of 2010, infrastructure-related activities have been coordinated with the National Financing Initiative for Research Infrastructure administered by the Research Council.

Project portfolio
The programme has a broad-based portfolio of projects in a number of generic areas called areas of expertise. From 2002-2011, a total of approximately NOK 240 million (34% of overall project funding) was allocated to 65 projects.

The figure below shows the amount allocated by the NANOMAT programme in the various areas of expertise.



Priority has also been given to investment in nationally-coordinated projects (NOK 147 million), infrastructure (NOK 66 million) and recruitment measures (NOK 20 million). In addition to allocations for infrastructure under the programme, the NANOMAT also awarded some NOK 180 million for the realisation of national infrastructure that gives academia and industry access to the expertise and equipment they need. The Norwegian Micro- and Nanofabrication Facility (NorFab), established in 2010, and the Norwegian Centre for Transmission Electron Microscopy (NORTEM), established in 2011, are good examples of this.

Selected trends – and challenges
Today, Norway attaches much more importance to national cooperation and coordination in national priority areas and to developing national infrastructure. The quality and capacity of research groups in the field have been enhanced, and Norwegian researchers publish more frequently in recognised scientific journals. Norway cannot be a world leader in every area; however, Norwegian researchers can and should carve out niches for themselves in which they can – or have already – become leaders. Areas in which Norwegian researchers already excel and in which Norway enjoys national competitive advantages should be further strengthened.

A long-term perspective and reliable funding are vital to enhancing quality and capacity in research. In certain areas, such as basic nanoscience, Norway lags behind internationally. More effective steps must be taken, for example by ensuring adequate access to modern infrastructure. As infrastructure is very costly, a concerted effort and national coordination are called for. There has also been an increase in international cooperation on infrastructure in recent years. No single country can alone shoulder the costs of building extremely large-scale infrastructure such as neutron and X-radiation facilities. It is crucial that Norway takes part in financing and using new, state-of-the art international infrastructure.

Nationally-coordinated project

Deeper understanding of the physics

Finding a material ideally suited to storing hydrogen is akin to searching for the proverbial needle in a haystack. Researchers at the Institute for Energy Technology (IFE) are attempting to speed up the search by first understanding the physics of catalysts more thoroughly.

Metal hydrides are a group of metal alloys, some of which can store large amounts of hydrogen within their molecular grid. Since the early 2000s, IFE has been a world-class research environment in alloys such as these.

Search clues
In two large-scale projects, IFE researchers have worked their way through several types of alloys considered promising. Most recently, efforts have concentrated on enhancing understanding of the physics of catalytic processes – which can point project manager Bjørn Hauback and his colleagues in the right direction in their search for the combinations of metals that impart the desired metal hydride properties.

After having tested and eliminated certain alloys once considered promising, such as alanates (aluminium-based compounds), the IFE researchers are now focusing mostly on boron-based alloys. Boron is a light element with many interesting properties. The researchers are also studying the properties of elements such as lithium, magnesium and calcium, with an eye to using them in metal hydrides.

Success criteria
The difficulty lies in finding a compound that needs little energy (heat) added in order to release its hydrogen atoms. A successful solution should be an alloy that can release its hydrogen at less than 150°C. When being loaded with hydrogen, the material should not require pressure higher than 50 bar.

Researchers involved in a related project at IFE are also studying metal hydrides for use in batteries.

PROJECTS
158516 Nationally Coordinated Projects in Materials for Hydrogen Technology
182040 Novel nanomaterials and nanostructured materials for hydrogen storage applications
203323 Novel Mg-based materials for advanced Ni-Metal Hydride batteries


Photo: Atle Abelse

IFE researchers Stefano Deledda (at left) and Magnus Sørby have studied a large number of alloys under intense X-radiation at the Swiss-Norwegian Beam Lines (SNBL) at the European Synchrotron Radiation Facility (ESRF) in Grenoble.

Modelling of molecules
In a project headed by Per-Olof Åstrand of NTNU, researchers developed techniques enabling them to devise models of molecules more easily. These have been used in designing both new catalyst materials and optical materials.

Project: 158538 Molecular modeling in nanotechnology

Surface-treating aluminium
By understanding the effects of trace elements on the surface of aluminium, scientists can reduce corrosion and wear. The results of a project headed by Kemal Nisancioglu of NTNU are already being applied to quality assurance of aluminium products.

Project: 158545 Modification of Properties of Aluminium Alloys by Surface Segregation of Nanoscale Trace Element Particles

Permeability in plastics
In a project headed by Jon Samseth of SINTEF, researchers studied the fundamental properties of complex polymers where nanoparticles have been added into the material. This can alter the density of membranes and open up new application areas.

Project: 158558 Using Nanoscale objects to Modify Structural Development at Different Length Scales

PART 2 / NANOMAT – QUALITY, CAPACITY AND EXPERTISE

Nationally-coordinated project

Sustainable energy technology

Oxides are one of the most promising material groups for the future of energy technology.

In 2008, nearly a dozen researchers and fellowship-holders (doctoral and post-doctoral) concluded the FOET project. Now the project participants from SINTEF, the University of Oslo and the Norwegian University of Science and Technology (NTNU) possess a great deal of knowledge and expertise in oxides – one of industry's most promising and valuable groups of materials for solving global climate and environmental challenges.

The three above-mentioned institutions are the Norwegian heavyweights in this field. The FOET project, headed by project manager Rune Bredesen of SINTEF, promoted collaboration between these well-established research environments. Thanks to knowledge gained from the project, the researchers have successfully competed for project funding from the EU and other funding sources.

Commercial applications
Two development companies have spun off from the project and activities carried out by the participating research groups. The University of Oslo and its partner NTNU founded the company Protia, which will produce proton conductors for use in fuel cells and membranes.

CerPoTech (Ceramic Powder Technology), another newly established spin-off company from NTNU, produces nano-sized oxide powders for use in fuel cells and membranes and many other purposes.

Another component of the project involved the development of a thin film deposited as an ultra-thin layer on silicon wafers, which has helped to raise the efficiency of solar cells.

A specialised database of oxides and their properties was also set up under the project. Scientists around the world can add data to the database as well as utilise its contents.

PROJECTS
158517 Functional Oxides for Energy Technology (FOET) (Nationally-coordinated project)
163560 Pulsed Laser Deposition Laboratory

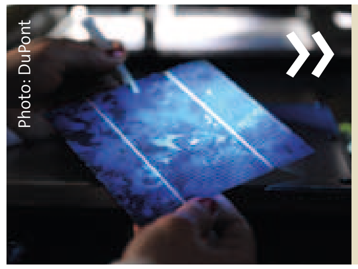


Photo: DuPont

Solar cells

Solar cells are made more efficient with an ultra-thin layer of oxide material.

Materials for hydrogen storage
In a project headed by Helmer Fjellvåg of the University of Oslo, researchers examined two classes of materials for storing hydrogen: nanophase hydrides and complex hydrides. Reducing particle size changes the chemical properties of a material, but makes it more unstable.

Project: 163550 Theoretical modeling of nanomaterials for hydrogen storage applications

Clay particles
Modifying the surface of clay particles makes them disperse better in oil. A project headed by Jon Fossum of NTNU resulted in new particles that students could use in electrorheological studies.

Project: 163558 Structure and Dynamics of Soft and Complex Nanomaterials

Viewing individual atoms
Scanning tunnel microscopy (STM) is very useful for mapping surfaces in a chemical environment, such as under electrochemical conditions. In a project headed by NTNU's Svein Sunde, this method generated a number of results related to hydrogen technology.

Project: 163576 Application of STM techniques for the study of electrocatalytic systems

Nationally-coordinated project

Nano-applications in ICT

Nanotechnology will play a pivotal role in the future of the ICT industry. Norwegian researchers have helped to develop an entirely new field.

The nationally-coordinated, large-scale ICT project in nanotechnology and nanoscience concluded in 2009 has proven to be one of the most important instruments for building national competence and collaboration in this field. The project has also raised the profile of Norway's academic expertise.

Putting a new spin on electronics
Spintronics is a field in which the international ICT industry is investing its highest hopes for developing future ICT solutions. The project has played a key role in establishing a strong Norwegian academic environment in this emerging branch of electronics. Sub-project manager Arne Brataas of NTNU garnered widespread academic acclaim for the publication of his article on electron spin in a carbon nanotube in *Nature*.

Superconductors and modelling
Another focus area of the project was theoretical and experimental work on superconductors. Main project manager Asle Sudbø of NTNU made the cover of *Nature* for an article on theoretical calculations of how hydrogen behaves under extreme pressure. This work has advanced the development of ultra-pure, ultra-hard industrial diamonds.

Sub-project manager Tom Henning Johansen of the University of Oslo was responsible for the experimental component of the project, which achieved some excellent, exciting results with optical thin films. This field is full of potential and is on the verge of becoming a major research area.

A new spin

Arne Brataas of NTNU coordinates the EU's spintronics activities, a testament to the strength of Norwegian expertise in this field.

The project has also helped to propel Norway to the forefront of simulation and modelling. Petroleum companies are drawing on this expertise; many of the top experts in reservoir technology gained their fundamental knowledge directly or indirectly from the project.

PROJECT
158518 Nationally Coordinated Project in Oxides for Future Information and Communication Technology

Catalysis 1
Researchers in a project headed by Mats Tilset of the University of Oslo have developed methods of producing stable metal-organic frameworks (MOF). The project has helped the University of Oslo to advance to the forefront in catalytic applications of this class of materials.

Project: 158552 New Catalysts for Activation and Functionalization of Alkanes

Catalysis 2
Using an electron microscope at the Technical University of Denmark, Anders Holmen of NTNU observed cobalt nanoparticles used in catalysts and has gained valuable insight into fundamental relationships in catalysis.

Project: 169673 Advanced transmission electron microscopy in catalysis

Aluminium alloys
Undesired trace elements can lower the quality of commercial aluminium alloys. A project headed by Kemal Nisancioglu of NTNU may help to reduce or eliminate undesired effects altogether when manufacturing and recycling aluminium.

Project: 182026 Exploitation of naturally formed nanostructured surface films on aluminum alloys

Nationally-coordinated project

Better products from complex materials

Complex materials are the basis for both new products and better-performing existing products. The COMPLEX projects have coordinated and streamlined Norway's research activities in this field.

Complex and advanced materials that self-organise are a relatively new field of research. These materials will play a significant future role in several industrial areas, contributing to advances in smart sensors, improved composites, additive materials that improve the characteristics of existing products, and not least entirely new materials with vast potential due to properties never before seen.

It is critical for Norwegian industry that academia and the research community succeed in developing expertise and producing specialists in this field. This expertise is what will enable the industry to maintain its international standing in the years to come.

The COMPLEX projects, headed by project managers Alex Hansen, Jon Otto Fossum and Knut Jørgen Måløy, have brought together leading research groups at NTNU, the University of Oslo and IFE, helping to coordinate and make optimal use of the three institutions' expertise and infrastructure. Approximately ten persons have completed a Master's or doctoral degree under the COMPLEX projects, which also funded many doctoral research fellows in the period 2003-2011. The projects have also enabled the researchers to build extensive international networks.

New products
The most valuable scientific results are related to understanding self-organising materials, in particular carbon nanotubes and nanocones. The company n-Tec, which was affiliated with the Physics Department at IFE, has developed a production method that has proven industrially robust, and has formed material into new, previously unknown shapes.

Another spin-off company from this research environment is Condalign, which develops advanced materials that improve the performance of products such as solar cells, batteries and electrical sensors.

Under the projects much effort was devoted to enhancing the understanding of the structure and composition of clay, which has led to a number of successful results ranging from a deeper comprehension of how self-organising clay structures are formed in nature and how water is transported and filtered in clay soil to how controlled inclusion of clay nanoparticles can improve the properties of functional plastic materials.

PROJECTS
158541 Nanostructured Soft and Complex Materials (COMPLEX) (Nationally-coordinated project)
163558 Structure and Dynamics of Soft and Complex Nanomaterials (COMPLEX)
182075 Michrorheology of nanostructured soft condensed matter (COMPLEX)
158554 Exclusion statistics transformation and application to mesoscopic systems

COMPLEX

The nuclear reactor located at Kjeller near Oslo was an essential instrument in the large-scale COMPLEX projects.

Nano-thin layer on metals
How do the first nanoparticles deposit on a surface of silicon? Ingeborg Kaus of SINTEF is heading a project to discover which forces affect the particles. The knowledge gained will be applied to create thin films on various metals.

Project: 182033 Fundamental study of the mechanism for deposition of sol particles on a substrate

Alternative to zeolites
Coordination polymers are hybrids of metal and organic polymers. A project headed by SINTEF's Pascal D.C. Dietzel has shown that these may be suitable for adsorbing hydrogen, methane and CO_2.

Project: 182056 Template based synthesis of nanoporous metal-organic frameworks with high surfaces areas

Hybrid catalysts
A project headed by Richard Blom of SINTEF is producing new structures of coordination polymers with open nano-sized pores and catalytically active sites within the pores. This knowledge has been incorporated in the EU project Functional Metal Organic Frameworks as Heterogeneous Catalysts (MOFCAT).

Project: 153869 Hybrid Materials

Peering into atoms

In Grenoble, Norwegian scientists are using intense X-radiation to figure out how solids are constructed. Thanks to cooperation between Norway and Switzerland, the researchers have access to Europe's largest synchrotron.

Since 1995, Norway and Switzerland have cooperated on sharing two of the 40 beamlines at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. A synchrotron can direct extremely intense, sharply focused X-rays that allow scientists to view materials at the atomic level, enhancing their understanding of the physics and chemistry of solids as well as the structure of biological crystals. Results are applied to areas such as catalyst development and hydrogen storage, and to enhance understanding of biological processes.

Researchers using the Swiss-Norwegian Beam Lines (SNBL) publish roughly 100 scientific articles annually, approximately 30 of which are typically authored or co-authored by Norwegians – far above the ESRF average.

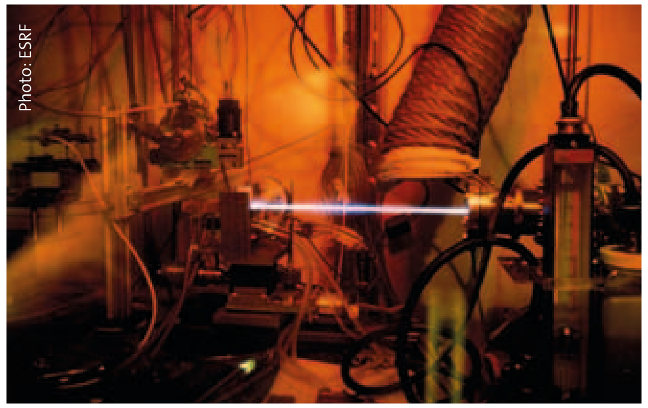
The SNBL activities are run by a company with eight permanent employees that is financed equally by the two countries. The Research Council of Norway covers two-thirds of Norway's membership fees, while the remainder is covered by the Norwegian participants IFE, the University of Oslo, NTNU, the University of Stavanger and the University of Tromsø.

PROJECTS

169676 Funding for Swiss-Norwegian Beam Lines (SNBL) at the ESRF, Grenoble, France

163563 New powder neutron diffractometer – PUS 2

The synchrotron in Grenoble is a vital tool for Norwegian researchers.



The beamlines in Grenoble reveal the behaviour of atoms.

Cellulose-reinforced plastic

Cellulose crystals and clay particles can be used to reinforce plastics, forming nanocomposites. In a project headed by Kristiina Oksman of NTNU, researchers developed new materials with good mechanical properties.

Project: 158534 Bio polymer based nanocomposites; Processing and Relationship between Structure and Properties

Materials with nanopores

New functional materials can be customised for use in fibre optics, catalysts and biosensors. A project headed by Mikael Lindgren of NTNU studied different types of these hybrid materials, some of which are being used in biosensors for diagnosing disease.

Project: 163529 Dendritic nanoporous materials with multifunctionality

Magnetic materials

Suzanne McEnroe of the Geological Survey of Norway (NGU) headed a project that studied the magnetic properties of minerals such as ilmenite and hematite at the nanoscale. The results are significant not only for producing high-density data storage that tolerates high temperatures, but also for understanding the earth's magnetism.

Project: 163556 The nature and origin of natural magnetic nanoscale materials

Bringing up the next generation of researchers

A national graduate-level researcher school is raising the calibre of researcher training for some 80 doctoral students in the field of nanotechnology for microsystems.

The researcher school is based on a network of Norway's key educational institutions in the field of microsystems. Giving doctoral students the opportunity to spend a portion of their training at other educational institutions and to use advanced equipment increases both motivation and quality.

Established in 2009, the researcher school will receive funding from the NANOMAT programme until 2013. Industry has been drawn into the training process, and a workshop where students can present their research and companies can discuss their development activities is organised each year.

Project manager Jostein Grepstad of NTNU has assembled a national team for researcher training, drawing from the extensive resources of NTNU, the University of Oslo, the University of Bergen, Vestfold University College and SINTEF. Industry is also represented by NCE Micro- and Nanotechnology, an industrial cluster of some 25 companies in Norway's Vestfold and Buskerud counties.

Besides organising courses and workshops, the researcher school provides funding to cover travel expenses and costs related to using laboratory equipment, as well as funding for one post-doctoral and two doctoral research fellowships.

PROJECT

190086 National Graduate-level Researcher School for Nanotechnology for Microsystems

Nanocones for storing hydrogen

A project headed by Arne T. Skjeltorp of IFE has shown that cone-shaped nanostructures have good properties for storing and releasing hydrogen at normal temperatures. The project results have led to an EU project.

Project: 163570 Nanocarbon for novel composites and functional materials

Expertise in metal oxides

A large-scale project headed by NTNU's Erik Wahlström has built up Norwegian expertise in nanostructures in metal oxides through international collaboration and the development of experimental methods.

Project: 182037 Magnetodynamics of Nanostructured Metal Oxides

Tool platform for materials research

Norway has a new laboratory for "looking inside" materials using nuclear magnetic resonance (NMR). A project headed by SINTEF's Bjørnar Arstad is seeking to make advances in catalysts and polymer materials, as well as other areas of materials science.

Project: 190367 FASTNMR – Solid-state Nuclear Magnetic Resonance spectroscopy for Material Science

Joint nano-platform in Bergen

Nanoscience research requires advanced laboratory equipment. In Bergen, several groups have joined forces to develop a national research platform.

Cooperation between the University of Bergen's Department of Biomedicine and Department of Physics and Technology comprises the core of the UiB Nano Platform. The equipment is distributed between the two departments.

The laboratories house equipment for photolithography and electron beam lithography, the latter of which uses electron beams to form surface patterns in materials. The University of Bergen has built up internationally recognised expertise in how to customise the properties of gold particles and large biomolecules in order to attach active molecules to surfaces.

The NANOMAT programme has made a significant contribution to the development of the platform by allocating funding to a project being carried out from 2008 to 2012 and headed by Bodil Holst of the University of Bergen. Billionaire Trond Mohn has also invested in the development of the platform.

Importantly, the new platform has led to closer collaboration between researchers in physics and biomedicine. Industry is also becoming increasingly involved in new projects, such as projects on solar cells and sensors.

PROJECT

190707 The UiB Nano Platform

Laying a foundation for new bone substance

By mimicking nature's way of constructing bone tissue, researchers at NTNU have developed methods of creating customised artificial tissue.

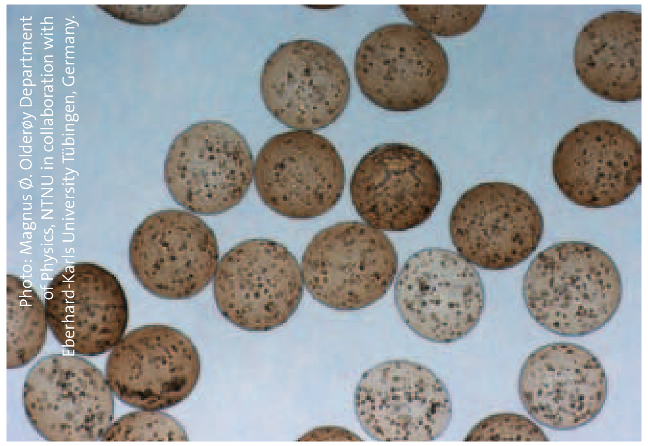
Living organisms have a unique ability to manufacture strong yet flexible composite materials, such as bone tissue, based on only a few types of building blocks. Tissue is formed when nano-sized mineral particles deposit onto a framework of a gel made of biopolymers. When the minerals attach themselves, the gel stiffens but remains flexible.

Researchers in a project headed by Pawel Sikorski of NTNU have successfully recreated this process in the laboratory. The team's concept involved getting the minerals calcium carbonate and calcium phosphate to deposit onto a framework of polymers in an alginate-based gel, thereby imparting the desired characteristics to the gel.

Trials showed that the new materials are compatible with human stem cells. This opens up future possibilities for healing bone fractures in older osteoporotic patients by injecting bioactive composites.

PROJECT

182047 Nanoscale Control of Mineral Deposition within Polysaccharide Gel Networks



Stem cells from bone marrow encapsulated in alginate particles.

PART 2 / NANOMAT – QUALITY, CAPACITY AND EXPERTISE

Physicists learning from each other

Theoreticians from three institutions pooled their knowledge and gained new insights into nanoscience. Their project resulted in three doctoral degrees as well.

One of their collaboration topics was the study of quantum control, i.e. the ability to control quantum mechanical systems using external instruments. This is done using mathematical simulations rather than physically. The very time-consuming simulations provide physicists with the opportunity to test their theories.

Project manager Jan Petter Hansen of the University of Bergen worked together with Arne Brataas and Asle Sudbø of NTNU and Yuri Galperin of the University of Oslo on the project, which ran from 2003 to 2007. One doctoral student was affiliated with the project at each university.

Joint meetings helped to expand the horizons of each and every project participant as well as strengthen Norway's basic competence in nanoscience. This knowledge was incorporated into other nanoscience projects running in parallel. Thanks to their participation in the project, each of the four theoreticians has received funding for new projects outside the NANOMAT programme.

PROJECT

158547 Quantum Transport in Nanoscale Systems

Nanosheets made to order

Researchers in Oslo have found a way to create nanosheets with precisely the characteristics desired. Although just 1-2 nm thick, these sheets can be up to 1 000 nm in diameter.

The project was featured on the cover of the *Journal of Materials Chemistry* in 2007.

At the atomic level, certain materials are constructed of strong layers held together by weak forces. Researchers have capitalised on this to separate the individual layers from each other, allowing them to stabilise nanosheets in solvents.

In a project headed by Poul Norby and Anja Olafsen Sjåstad of the University of Oslo, researchers have developed and optimised methods of producing nanosheets which maintain the chemical composition and atomic arrangement. These sheets can then be assembled into new types of nanomaterials and composites.

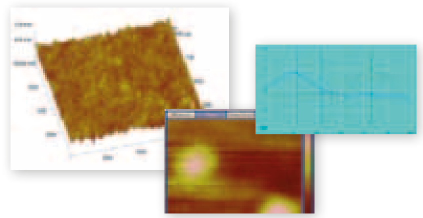
Basic competence in producing and characterising nanosheets has been developed at the University of Oslo in collaboration with IFE and SINTEF. This competence is being applied to develop new catalysts and nanocomposites and in further research in surface chemistry. One potential application is photocatalysis for purifying water using sunlight. Another is catalysts for converting natural gas into synthesis gas; the company Abalonyx is building on this expertise.

PROJECTS

158519 Preparation of new chemically nanostructured materials via exfoliation of layered materials

182077 Novel catalysts and oriented oxide thin films from exfoliated nanosheets of layered materials

163565 Novel nanostructured materials by chemical methods

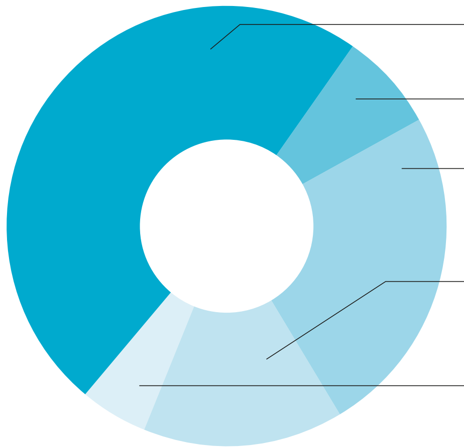


Atomic force microscope (AFM) image of nanosheets on a surface. The nanosheets are roughly 1 nm thick with a diameter of 20-30 nm.

Internationalisation

Since its launch in 2002, the NANOMAT programme has focused on promoting the internationalisation of research and the mobility of Norwegian researchers. Building strong, recognised research groups helps to make Norway an attractive destination for international researchers. The programme has also implemented specific measures to provide researchers with the opportunity to conduct a research stay abroad. In addition, the programme has taken part in international initiatives and activities (such as the ERA-NET scheme, the ENIAC Joint Undertaking to coordinate European nanoelectronics research, the Nordic Top-level Research Initiative, and bilateral cooperation) which provide researchers with the opportunity to participate in the international arena and in international fora (such as the OECD, COST, and the EU) where policy design and plans for issuing international research funding announcements are discussed.

Project portfolio
According to the external evaluation of the NANOMAT programme, 83% of the programme managers believe that the programme has to a great or some extent helped to increase international cooperation. Of the publications issued under the NANOMAT programme, 55% were international co-publications. As much as 80% of all publications from innovation projects were international co-publications. The project managers themselves highlight involvement in joint research projects and co-publication as the most important international aspects of project participation. This has helped to lay an excellent foundation for strengthening Norway's international orientation in the field of nanotechnology and advanced materials. The figure below shows the programme's allocations to specific international initiatives (6% of the project portfolio).



Selected trends – and challenges
There is growing awareness in the Norwegian research community of the importance of internationalisation and the need to participate in the international arena. Today, Norwegian research groups are much more attractive partners for international cooperation than they were 10 years ago. They are now reasonably successful in competing for EU funding, particularly in the areas of materials and energy. They have, however, been much less successful in the area of basic nanoscience. Equipping Norwegian research groups and industrial players with what they need to "take home" a larger portion of the funding Norway channels to EU research and innovation initiatives each year remains a challenge.

Knowledge no longer knows national boundaries. Knowledge is developed globally, and industry uses national knowledge as long as it is competitive. The markets have become more global as well. In the past national borders served as protective barriers, keeping competition out, but now even domestic markets have become globalised. It is therefore a challenge to make Norwegian knowledge and industrial environments visible and attractive internationally so that they can take part in global knowledge and industrial development.

Norwegian industry, with its associated knowledge development activities, is moving to locations and markets where the framework conditions are favourable. Norway should therefore strive to exploit its national competitive advantages, drawing the attention of global knowledge and industry players by promoting excellence in Norwegian R&D and creating appealing incentives for international industry.

Nanocapsules to deliver cancer drugs

A gel capsule just 50-200 nm long can be designed to find cancer cells and release medicine into them. A project under the ERA-NET MATERA is leading the way towards cancer treatment with fewer side effects than current treatments.

Chemotherapy treatments kill cancer cells but are an ordeal for patients, largely because the drugs attack many healthy cells as well. Targeted drugs, however, can substantially improve treatment for cancer patients – and promising trials have brought these medicines closer to realisation.

Seek out, attach to, and kill

When a patient receives an injection of medicine with specially designed nanocapsules, the first obstacle to overcome is the patient's own immune system. Because white blood cells will attempt to disarm each nanocapsule, the researchers coat the capsule surface with molecules that protect it. The next challenge is getting the nanocapsules to find the cancerous cells and attach to those cells only; this is the function of customised molecules on the capsule surface. Once the capsule has attached itself to the cancer cell, it must push through the cell wall – then when inside, the capsule dissolves so the drug can spread throughout the cancer cell and kill it.

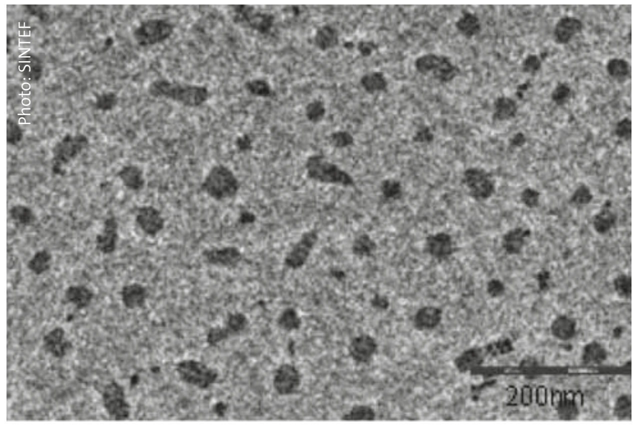


Photo: SINTEF

Silica capsules with particles averaging just 30 nm in size, as seen through a transmission electron microscope.

International collaboration

For several years SINTEF has been working on customising such nano-sized capsules; in 2007 the institute launched NanoMedPart, a MATERA project, together with one Polish and one Israeli partner.

For project manager Christian Simon of SINTEF, the project was a chance to greatly accelerate the development of nanocapsules that deliver cancer drugs. One advantage of MATERA projects is that they require fewer partners and have simpler reporting procedures compared to the large-scale EU projects.

The researchers investigated a number of methods for forming the right nanocapsules and matching them with the right surface molecules. They also demonstrated that nanocapsules are biocompatible, i.e. not harmful to the body. The trials were done on cells *in vitro* (isolated outside the body); the next phase will be animal trials. The project partners are now seeking industrial partners with activities in this field.

PROJECT

179590 Multifunctional Particulate Systems for Nanomedicine

Eliminating hormone disruptors

In a MATERA project, researchers headed by SINTEF's Per Martin Stenstad successfully removed hormone disruptors from wastewater. The enzyme laccase, which breaks down endocrine disrupting chemicals, was bound to nanostructures at the wastewater treatment facility.

Project: 189716 Laccase-Nanoparticle Conjugates for the Elimination of endocrine disrupting chemicals from wastewater in bioreactors

Rocks with memory

Suzanne McEnroe of the Geological Survey of Norway (NGU) heads a MATERA project in which researchers are studying rocks that "remember". Very stable, nano-sized magnets occur at the interface between the minerals ilmenite and hematite.

Project: 189721 Novel Nanomagnetic Oxide Composites: Giant Exchange Bias Storage Devices

Heat exchangers without bio-growth

In a MATERA project headed by SINTEF's Stein Tore Johansen, researchers developed a mathematical model for how particles deposit onto the interior surfaces of industrial heat exchangers. The project results will help to reduce particle deposition inside heat exchangers.

Project: 179587 Modeling of particle deposition phenomena in heat exchangers

Gaining knowledge abroad

Norwegian students have sharpened their skills and built valuable networks of contacts through their studies abroad at internationally respected universities.

A project headed by Helge Weman of NTNU involved the exchange of Master's students and doctoral research fellows with the Colorado School of Mines. In this project the researchers studied the formation and characteristics of nanothreads made of zinc oxide, a material with potential to raise the efficiency of hybrid solar cells. These cells combine the advantages of both organic and inorganic semiconductors.

Researchers at NTNU and SINTEF achieved promising results using silicon and sapphire as substrates for growing nanothreads. The team developed a method of examining each individual nanothread in order to study and characterise thread structure and optical properties.

The project's results have been useful in subsequent studies of gallium arsenide nanothreads and for developing higher-efficiency solar cells.

Evolution of materials

The University of Oslo's Chris Erik Mohn received funding for a three-year post-doctoral fellowship which financed stays as a guest researcher, first at the University of Bristol in the UK and then at Montpellier 1 University in France. Mohn used his fellowship grant to develop genetic algorithms, a type of artificial intelligence.

These algorithms enable him to model how complex materials' chemical composition can undergo a kind of Darwinian evolution. Mohn's method is now helping several materials scientists at the University of Oslo. In another part of the project, he studied the molecular structure of superionic conductors, work which is now aiding the development of solid oxide fuel cells.

PROJECTS

182092 NSF-European Materials Cooperative Activity. Nanostructured oxide thin films for organic/inorganic solar cell applications

169713 Genetic approaches to complex materials

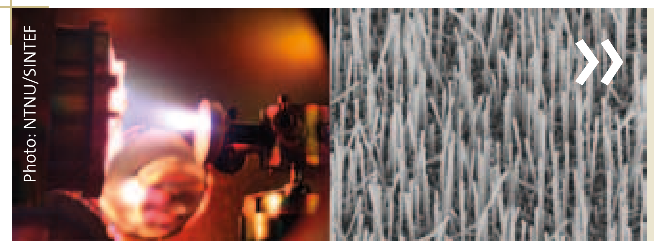


Photo: NTNU/SINTEF

Exchange

Extensive exchange of researchers and students with international research groups has helped to build up a high level of expertise at NTNU in areas such as characterisation and production of nanothreads.

Particle flow

Jan-Ludvig Vinningland of the University of Oslo has refined the numerical model for granular flow. His work, including two years at the Swiss Federal Institute of Technology (ETH) in Zürich, has extended the model and enhanced the understanding of particle movement in a fluid.

Project: 178533 A numerical and experimental study of flow and instabilities in concentrated colloidal suspensions

Single-wall carbon nanotubes

Carbon tubes with only one wall are useful for reinforcing materials. The challenge lies in distinguishing them from multi-wall nanotubes. The University of Oslo's Juan Cardenas, working also in Sweden, has studied how spectroscopy may facilitate this process.

Project: 178556 Conformation and Physical Properties of Single Wall Carbon Nanotube-Biomolecule Hybrids

Nanocooling

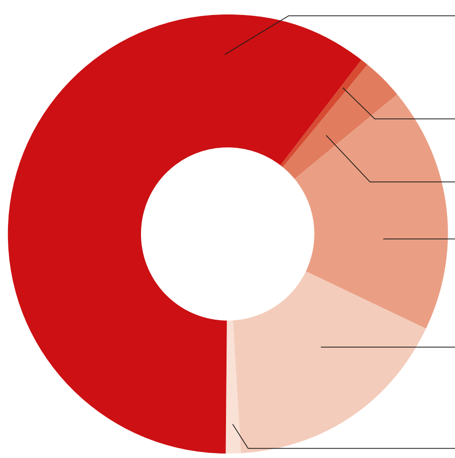
Nanofluids – fluids with a uniform distribution of nanoparticles – can raise cooling performance in products such as electronics. Matteo Chiesa, in his post-doctoral research at the Massachusetts Institute of Technology (MIT), has studied how the properties of nanoparticles work.

Project: 169659 Heat Transferability in Nanofluids

Value creation

Since its launch in 2002, the NANOMAT programme has focused on basic competence-building. Nevertheless, the programme awarded its first grants to industry-oriented projects as early as 2004. As from 2006, the programme received a larger allocation from the Ministry of Trade and Industry, and correspondingly increased its funding of innovation projects for the industrial sector, pre-projects and commercialisation measures. The programme also employed knowledge-building projects for industry and large-scale institution-based projects as key funding instruments to direct the attention of the research community (academia and independent research institutes) to the needs and problems of trade and industry.

Project portfolio
The programme now has a broad-based portfolio of industry-oriented projects. From 2002-2011, a total of NOK 214 million was allocated to 53 projects (30% of overall project funding). In addition, some 100 participating companies contributed about NOK 200 million of their own resources to the projects. The amount of funding awarded ranged from NOK 100 000 for pre-projects to NOK 36 million for a single large-scale institution-based project. The figure below shows the distribution of funding by type of support.



Selected trends – and challenges
In recent years Norwegian trade and industry has shown greater interest and capability in transforming interdisciplinary knowledge of materials and structures into industrial products. The first nanotechnology-based products have been produced at industrial scale and are available on the market. Companies are also using nanotechnology to improve existing products and create processes that use less energy and fewer raw materials. In the area of nanostructured materials in particular, the road from the laboratory to industrial application has been relatively short for new technology. It is primarily established industry that has made use of generic technology. Facilitating the establishment of new companies whose core competence is nanotechnology is a challenge.

The number of nano-based products and companies is expected to rise in the years to come. It will be essential to clarify questions relating to legal issues, regulation and potential negative side effects of these products. A lack of knowledge about these important issues is slowing down market introduction.

Successful powder

Norway is home to a strong research community in ceramics. Success has come from starting small – in powder form.

Ceramic powder is the starting point for a great many advanced materials – with applications in practically every industry. It can be used, for instance, in most of the components that go into high-temperature fuel cells, ferroelectric materials and high-temperature superconductors. Ceramic powder-based materials are used in innovative technology such as catalytic membranes and other energy-related technology, contributing to the development of new, more environment-friendly energy technology.

New company

With the help of a project under the programme Commercialisation of R&D Results (FORNY) that received funding from the NANOMAT programme, a new company was founded by NTNU's Kjell Wiik, Tor Grande and Mari-Ann Einarsrud. The company, CerPoTech, is based on results from a number of powder/ceramics projects carried out at NTNU.

Using a spray-pyrolysis facility, the company now produces substantial quantities of high-quality, multi-component ceramic powder. CerPoTech can produce complex powder compositions with homogenous particle size and crystal size as small as 10 nm. This powder provides a strong basis for manufacturing high-quality, high-density materials. The tiny building-block particles also allow the materials to be structured at the nanoscale, which opens up opportunities to further improve the materials' mechanical and functional properties. The focus of the project was on inventing new and better materials, as well as understanding the fundamental processes of developing such materials.

Europe and the US

NTNU Technology Transfer, the project owner of the nanopowder project, played a pivotal role in the process of translating valuable scientific findings into commercial success. CerPoTech, marketed as a partner for R&D companies and institutions, offers products with applications such as replacing environmentally hazardous lead in the electronics industry and in renewable-energy materials such as fuel cells and ceramic membranes. CerPoTech has constructed a first production line for small-scale production and delivery to customers in Europe and the US.

PROJECT

183890 Value added products based on ceramics nanosized powders produced by spray pyrolysis (FORNY)

Faster-hardening epoxy

SINTEF's nano-sized particles of hybrid polymers can accelerate the hardening of epoxy systems and reduce emissions of formaldehyde from wood composite plates, shows a project headed by Ferdinand Männle of the company Sinvent.

Project: 179973 Verification of technology – nanoparticle additives for improved curing of thermoset polymer systems (FORNY project, with funding from the NANOMAT programme)

Metal hydrides for hydrogen applications

In a project headed by Mariann Ødegård of the company Campus Kjeller, researchers studied how to commercialise production of metal hydrides for storage tanks and other equipment for hydrogen.

Project: 187355 Metal hydride technologies for production of advanced hydrogen storage materials and hydrogen supply systems (FORNY project, with funding from the NANOMAT programme)

Stronger composites

In a pre-project headed by Reidar Stokke, SINTEF identified how to use nanotechnology to improve the properties of composites with continuous armoured fibres, which are used to reinforce thermoset polymers such as polyester and epoxy.

Project: 176115 Utilising nanotechnology for composite materials

Strong focus on membranes

Membranes are a small but important segment of materials research at NTNU. The petrochemicals industry and energy companies alike are very interested in the findings.

There are many industrial application areas for thin-film composite membranes, including at desalination facilities and in industrial processes. Membranes are vital to processes such as desalination, butanol purification and pressure retarded osmosis such as osmotic power.

The international membrane industry is sizeable, with a high degree of product development. In the past 10 years, Norwegian research groups have become a part of this industry, thanks in part to Statoil's petrochemical activities and Statkraft's ambitions of developing osmotic power technology.

At NTNU, Inger Alsvik (pictured) has been working with May-Britt Hägg and Tom Nils Nilsen on developing a membrane for pressure retarded osmosis for osmotic power. The trio have achieved promising results.

Key component

At NTNU, May-Britt Hägg headed a project focused on raising the efficiency of the various processes. One of the project's researchers has now developed and patented a plastic material suitable for production in a very thin shape which allows it to attach well to a support structure.

Membranes for osmotic power must be able to withstand certain conditions that can only be tested at a larger scale. The researchers are testing their membrane's tolerance to the build-up of deposits from salinisation and impurities in the water.

Previously, Hägg had founded the company MemfoACT, together with Jon Arvid Lie and Arne Lindbråthen, based on research on various membrane materials. The company has achieved success by developing a unique membrane-based separation technology with a number of industrial applications. With strong industrial partners and pilot customers, the company is poised for further growth.

PROJECT

187266 Parameter optimization in preparation of membranes for osmotic processes

Mimicking the giant sea snail

The shell of the red abalone sea snail is constructed of plate-shaped crystals with remarkable tensile strength and fracture toughness. In a project headed by Rune Wendelbo, Abalonyx developed methods for synthesising nanosheets with properties similar to the sea snail's.

Project: 176231 Biomimicking nanocomposites – thin films and super-strong materials

Nanoparticles of natural gas

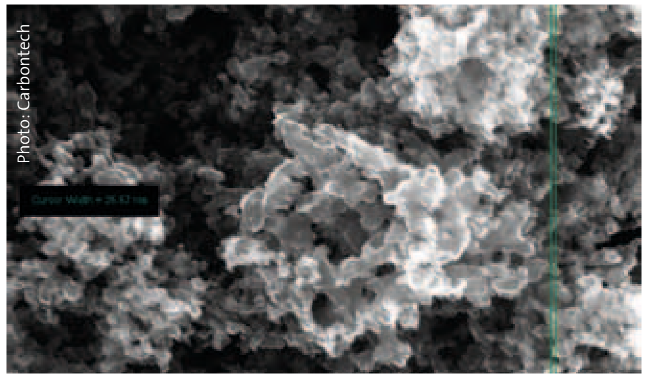
Natural gas (CH_4) may be an important source of carbon nanoparticles. A method developed in Bergen ensures uniformly sized carbon particles that can be used in dyes, materials reinforcement and modern electronics.

For over a decade, the Bergen-based company Carbontech has been developing the process for producing such nanoparticles. Having passed the research and pilot stages, the company is now testing a prototype facility near Bergen, using natural gas from the Troll field. The next step may be a small production facility in Høyanger. But Director Arne Godal has grander ambitions: by combining a nanocarbon particle production facility with a gas-fired power plant, the plant becomes more profitable while cutting its CO_2 emissions in half.

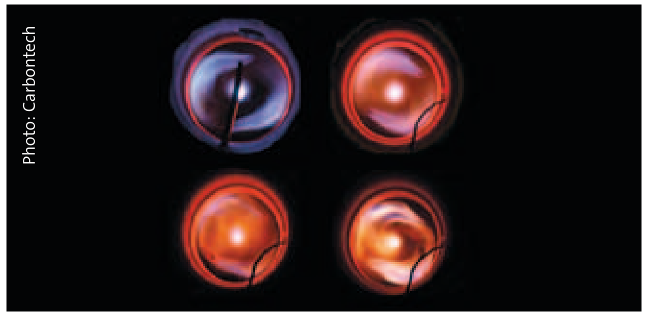
The nanoparticles are formed when natural gas is blown into a chamber with temperatures of 3 000 to 4 000°C. The particles become uniformly sized carbon particles with a diameter of roughly 20 nm. Their size can be tailored by controlling the temperature and gas flow into the reactor. The process converts more than half of the natural gas carbon to nanoparticles, while the remainder is a hydrogen-rich natural gas mixture that releases more energy and lower CO_2 emissions than natural gas.

PROJECT

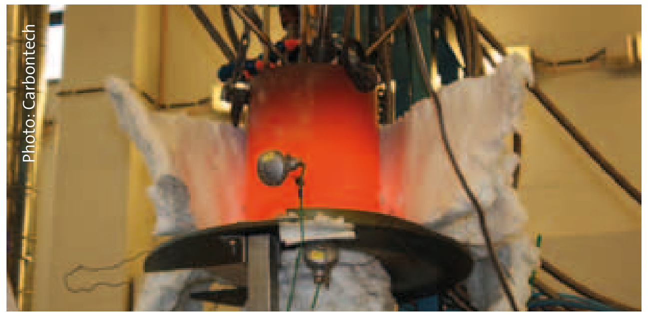
176392 High-quality nanocarbon from natural gas



The nanoparticles form in the shape of grape clusters.



Flames of different temperatures.



Pilot facility for production of carbon nanoparticles.

New paint for ships
The company Re-Turn carried out a pre-study of how to use epoxy combined with carbon nanotubes for painting a ship's hull in order to cut fuel consumption. Paal Skybak was project manager.

Project: 179159 Study of carbon nanotube-modified epoxies as toxin-free, solvent-free primer/coating/paint for marine applications

Silicon foam
By using micro-sized silicon particles in an aqueous solution, silicon foam can be formed with nano-sized pores. Gylseth AM Research, with Duncan Akporiaye as project manager, has examined commercial applications.

Project: 179200 Commercial application of Nano-porous silicon

Characterising silicon foam
Based on project 179200, SINTEF has gained an understanding of the physical and chemical properties of a nanoporous silicon foam. Headed by Knut Thorshaug, the project has laid the foundation for tailoring the material's properties and quality in the production process.
The project was not completed.

Project: 181848 Commercial application of Nano-porous silicon

Graphene-based layer for rollable computer screens

A layer built up of nanoparticles of graphene can make flat screens and solar cells flexible. The company Abalonyx is developing a layer that conducts electricity but is light-permeable.

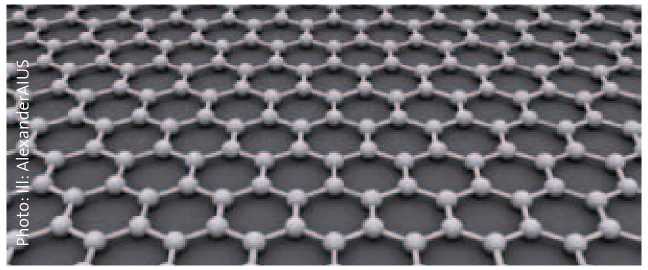
Rune Wendelbo, the founder of Abalonyx, has been researching the surface structure of sheet-shaped nanoparticles. He has developed a method of altering the surface of these nanosheets so that they keep separate when dispersed in water. The nanosheets, just 0.3 to 1 nm thick, can be from 30 to 1 000 nm in length and width. The layer is formed by manipulating the nanosheets so that they slide like "flying carpets" down to the base of the layer until the layer reaches a thickness measuring just tens of nanometres. To achieve an even layer, the particle sheets must self-organise, i.e. distribute themselves neatly without clumping.

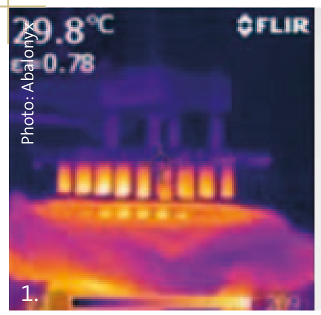
Graphene is exceptionally conductive, but there is high resistance in the contact between the individual graphene particles. In searching for additives, the researchers at Abalonyx found a disulphide with equally good conductivity as indium tin oxide. Their intention is to mix the disulphide into the layer for better contact between the individual graphene particles.

Abalonyx began using graphene as a material before the Nobel Prize in Physics was even awarded to its discoverers. Now the company is attracting more interest from industry, including in Japan.

PROJECTS

193248 Flexible, transparent conductive layer
210762 Pilot production of graphene derivatives





A layer of nanoparticles

1. Samples after heat treatment, photographed with a heat camera.
2. This business card is easy to read through its transparent, electricity-conducting layer. Graphene areas are shown in grey, and sulphide-based in green.

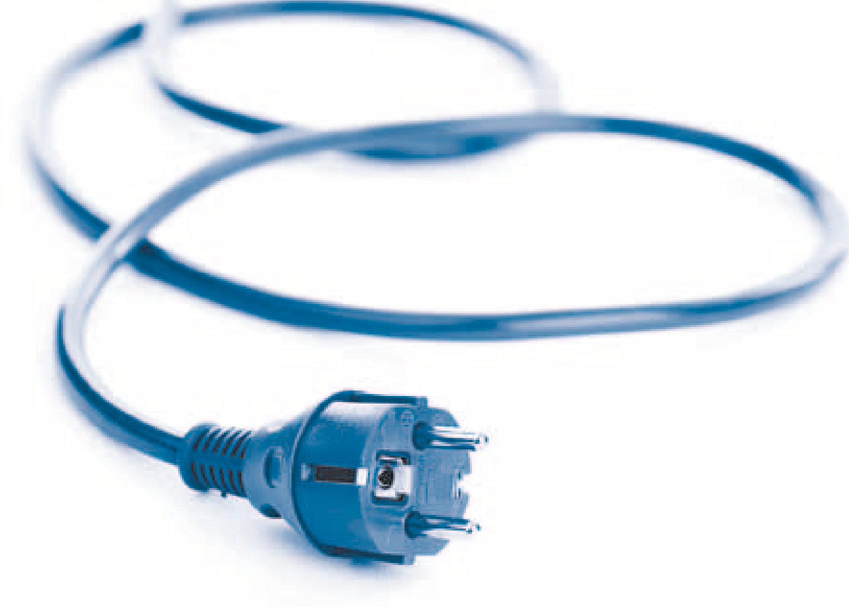
Nanocoating
The company Microbeads carried out a pre-study, with Anne Kari Nyhus as project manager, of how to use nanoparticles, alone or in combination with Ugelstad particles, in various water-soluble coatings.

Project: 182115 Pre-study of nanoparticles for use in coating applications

Nanostructures for joining aluminium
The HyBond project, headed by Ulf Roar Aakenes, developed a tool machine for joining aluminium in a "cold" state. The advantage over conventional hot welding is that cold joining does not weaken the metallic construction.

Project: 187247 Hymen bonding as a method for joining aluminium

Energy

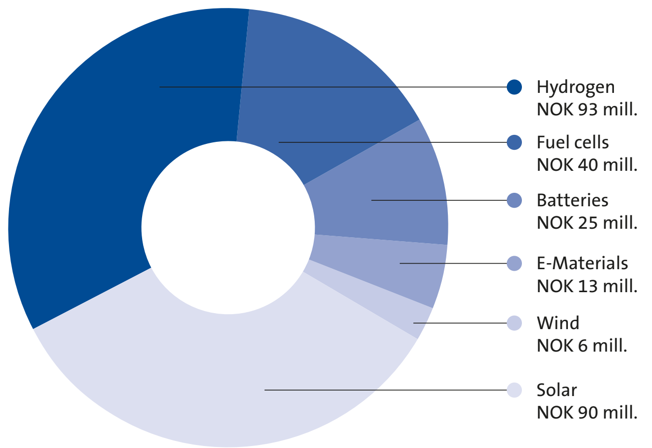


From the outset, the NANOMAT programme has given priority to research applicable to the area of energy and the environment. The programme has funded projects ranging from basic research projects with very long-term objectives, to much more market-oriented projects. The main focus has been on solar and hydrogen technology, in addition to other forms of renewable energy, batteries and fuel cells. The broad-based political agreement on climate policy achieved in the Storting in 2008 resulted in extra allocations to the programme, which was then able to place special focus on energy-related research in the latter part of the programme period.

Project portfolio

From 2002-2011, the programme allocated a total of NOK 267 million to 34 projects of relevance to the energy sphere (approximately 37% of overall project funding). Of these projects, 15 were researcher projects, 13 were innovation projects in the industrial sector, three were knowledge-building projects for industry, one was a large-scale institution-based project, and two involved commercialisation measures. The amount of funding awarded ranged from NOK 42 million to NOK 100 000 for a pre-project. The focus of the project portfolio shifted from a focus on hydrogen storage in the early years of the programme towards solar energy in more recent years.

The figure below shows the distribution of funding by technology area.



Selected trends – and challenges

Nanotechnology holds great potential for realising new solutions and breakthroughs in (renewable) energy – both in the form of materials choices and (nano)technological solutions. Research activities funded by the programme have led to technological breakthroughs, for example, in new materials for fuel cells and solar collectors, and several projects have produced research findings of top international calibre. When it comes to solar cells, in addition to lowering production costs there is currently extensive focus on raising efficiency, either by modifying existing silicon-based technology or by introducing entirely new solutions. With regard to battery technology, researchers are working to make batteries more efficient and lighter by using nanostructured materials in the surface layer on battery electrodes, among other things. Fuel cells and hydrogen offer alternatives to petroleum-based energy and may help to meet the growing need for reduced greenhouse gas emissions – provided that hydrogen can be stored safely and effectively, for example in personal vehicles.

Technologies within the area of energy and the environment are becoming increasingly diverse, and focus on osmotic power, wind power, wave energy, bioenergy, membranes and geothermal energy is growing. There is a need to produce lighter materials of high strength and stiffness for wind turbines. In the area of bioenergy, efforts to exploit biological carbon found in wood biomass are underway, for example, to produce fuel. Meanwhile, new nano-based membranes are being developed for use in osmotic power production – which is essential if this technology is to be commercially interesting.

Efficient, stable car batteries

Lithium ion batteries – such as those in our laptop computers – are excellent candidates for use in electric vehicles as well, provided researchers are able to solve challenges related to safety and battery lifetime. What is needed is a deeper understanding of the surface layer of the battery electrodes.

Lithium ion batteries provide the highest energy density of any battery type, dominating the market for transport, but improvements are needed to meet the requirements of personal vehicles.

Just thin enough
One challenge in refining lithium ion batteries is finding the optimal thickness of the surface layer that separates the graphite anode from the electrolyte. The anodes are made of powdered graphite, which is comprised of pure carbon particles roughly 15 microns in size. The thin layer on the surface of these particles prevents them from dissolving in the aggressive electrolyte. But if this protective layer is too thick, it will prevent the lithium ions from reaching the electrode and more lithium becomes bound up, which causes the battery to lose its capacity over time (known as irreversible capacity loss). Too thick a surface layer also raises the risk of triggering heat-producing chemical reactions in the interface between the layer and electrolyte. In extreme cases, such reactions can cause a runaway heat build-up that leads to a battery catching fire.


Photo: Shutterstock

Finding answers for industry
A project headed by Ann Mari Svensson of SINTEF and involving several industrial partners has set out to minimise irreversible capacity loss. By studying the structure of the electrodes' surfaces and finding out precisely what occurs there chemically, the researchers are seeking to provide industry with valuable information on how to produce higher-quality electrode materials that avoid major losses with the initial charging. Established in 2009, the project will run through 2012.

Safety considerations are one reason that purely electric vehicles and plug-in hybrid vehicles have been slower to market than expected. The researchers are searching for correlations between the structure and surface chemistry of carbon anodes and their effect on the anodes' lifetime and thermal stability.

PROJECT
195431 Carbon Materials for improved stability of anodes Li-ion batteries

Higher-efficiency fuel cells
In a project headed by Signe Helene Kjelstrup, researchers at NTNU and SINTEF are seeking to raise the efficiency of hydrogen fuel cells by developing new functional layers in proton exchange membrane (PEM) fuel cells.

Project: 203502 Nanodesign to Improve the Catalytic layer of the Polymer Electrolyte fuel cell (NICE)

Separating different silicon isotopes
The company Isosilicon has developed a patent-pending method of separating different silicon isotopes from one another. In a project headed by Dag Øistein Eriksen, researchers also tested the separated gas as a surface material for solar cells.

Project: 181769 Utilisation of monoisotopic 28Si

Higher-efficiency solar cells
A group headed by the University of Oslo's Bengt Gunnar Svensson has developed new solar cells in which different layers of treated silicon are covered with an anti-reflective coating. The current from such solar cells travels through transparent conducting oxides.

Project: 169656 High efficiency Si-based solar cells employing nanostructured layers

Proton conductors spare the environment

Proton conductors may play a valuable role in achieving a climate-friendly, higher-efficiency energy system.

Conventional production of liquid fuels from coal and natural gas uses Fischer-Tropsch synthesis, which is not energy-efficient and furthermore produces major CO_2 emissions. A new method based on proton conductors, however, can raise efficiency from 50 to nearly 65% while cutting out CO_2 emissions entirely.

Competitive
Researcher Christian Kjølseth of the University of Oslo is also the head of technology at the company Protia. He is heading a project to develop a method of manufacturing ceramic proton conductors made of a rare earth tungsten salt. The proton conductors would be used in producing liquid fuel from natural gas that can compete pricewise with conventional production methods.

The company is launching a small pilot facility at Oslo Innovation Center with the initial objective of producing just one litre of fuel per day. The next step will be a pilot facility producing over 1 000 litres per day.

In a parallel project, the company will introduce its technology to the market through a demonstration project that it hopes will contribute to the rapid phasing out of conventional, inefficient, polluting methods.

The projects have scientific affiliations with a SINTEF project headed by Rune Bredesen, who has experience with the same materials.

PROJECTS
195912 Fabrication of Robust Ceramic Proton Conductors
210765 Rapid market introduction of new membrane technology for clean energy applications: upgrading the ProboStat with ceramic proton conductors
182090 Development of highly efficient nanostructured SOFCs integrating novel Ln(Nb,Ta)O4-based proton conducting oxides
187441 Electrolyte for Proton Conducting Fuel Cells made with La(Nb,Ta)O4 Verification of manufacturability


Photo: Protia

University experiment

The University of Oslo's Reidar Haugsrud (at left) and Christian Kjølseth of Protia set up an experiment to characterise the proton-conducting properties of a rare earth tungsten salt.

Gluing solar cell conductors in place
Instead of soldering or welding the conductors that carry current from the solar cells, a project headed by Mark Buchanan of the company Norsk Solkraft studied the use of conductive adhesives with nanoparticles to hold the conductors in place. The project was not completed.

Project: 181823 Nano-particles in adhesive conductive materials

Lower-cost production of solar cells
All solar-cell producers wage a constant battle to lower their costs. In a project headed by Martin Kirkengen of REC Solar, the company developed new technology and a patent-pending production method.

Project: 181839 Hetero-junction Si based solar cells

Alternative process for solar cell production
Producing silicon for solar cells requires substantial energy and significant investments. In a MATERA project headed by Torgeir Lunde of the company HyCore, researchers studied an alternative process requiring less energy and lower investment costs.

Project: 183606 Next generation solar grade silicon and solar cells technology

A leading European centre for solar cell research

The Institute for Energy Technology (IFE) is home to one of Europe's leading research environments in several niches of solar cell research.

Solar cells are one of the fastest growing energy technologies on the international market. Solar cells hold great promise in helping to meet the global demand for large quantities of environmentally and climate-friendly energy. First, however, the technology must become even cheaper and more efficient – and researchers at IFE are doing their part by developing super-thin, silicon-based solar cells that will pave the way for the inexpensive, super-efficient technological solutions of the future.

Centre for Environment-friendly Energy Research (FME)
Erik S. Marstein is heading a seven-year project to develop production methods for inexpensive, high-efficiency solar cells – with a particular focus on reducing energy loss from surfaces. The project has also yielded results in nano-, thin-film and materials technology.

Developing surfaces that are entirely black, for instance, allows for absorbing as much sunlight as is physically possible. Another example is the development of completely new solar-cell materials based on metal hydrides which can be used in tandem cells, with an extremely high efficiency potential. The researchers' work with metal hydride films has attracted international attention, as the films possess other interesting properties such as reversible colour change upon exposure to light, known as photochromism.

Other projects
The project has scientific affiliations with the CONE project, headed by Bengt Gunnar Svensson of the University of Oslo. The researchers are developing new conducting oxides and nano-structured surfaces for future solar cells. Some of the expertise in these projects was gained from the previous project Functional Oxides for Energy Technology (2003-2008), which was headed by SINTEF's Rune Bredesen and received funding under the NANOMAT programme.

PROJECTS
181884 Thin and highly efficient silicon-based solar cells incorporating nanostructures
181882 Conducting Oxides and Nanostructures for Energy Technology
158517 Functional Oxides for Energy Technology

Lab tests

New materials are tested at IFE's solar cell laboratory.

Disproving a silicon hypothesis
Solar cells with only one silicon isotope were thought to be most efficient. When researchers in a project headed by Dag Øistein Eriksen of the company Isosilicon sought to exploit this effect, however, the hypothesis turned out to be incorrect and the project was terminated.

Project: 193329 Isotope separation of silicon for use in the photovoltaic industry

Solar cells at lower cost
Thin-film technology can drive down the cost of solar cells. A project headed but later halted by Ole Martin Grimsrud of the company Scatec made progress on new materials for solar cells.

Project: 195193 Novel low-cost nano-silicon solar cells

Storage tanks for hydrogen
Metal hydrides are suitable for use in storing hydrogen in compact tanks and compressors. In a project headed by IFE's Volodymyr A. Yartys, researchers developed technology for the European Space Agency and later applied for a patent.

Project: 169736 Nano science for new advanced metal-hydrogen systems towards applications

Social perspectives and "doped" solar cells

Since third-generation solar cells will be able to convert far more solar radiation, they will play an important role in securing an adequate global supply of energy. But what about the health, safety and environment (HSE) aspects of the production process? And what do societal stakeholders and consumers think?

In an integrated project – a new type of project at the Research Council – the technological development of new solar cells will go hand-in-hand with social science research. The project's technologists will develop solar cells that will surpass today's output while being simpler to produce than the equally high-efficiency solar cells being used in satellites – all of which will lower the cost of producing electricity. Meanwhile, the technologists themselves will also be the subject of study.

This is a new way of carrying out a research project, in which half the project is devoted to developing advanced technology and examining the HSE aspects involved, while the other half studies interest groups' viewpoints on the technology and its development process. The objective of this project headed by Turid Worren Reenaas of NTNU is to develop socially robust solar cells in accordance with society's wishes and what it finds acceptable.

Throughout the project, which runs from 2011 to 2014, the researchers will examine how the discussions across disciplinary dividing lines influence the development and design of the technology.

Doping
The new solar cells are being developed using knowledge gained from a previous technology project, applied now to creating heavily doped semiconductors. Doping is the enhancement of solar-cell conductivity by adding a sufficiently high number of atoms from a chemical element other than the semiconductor. Inside the new solar cell, a heavily doped layer is placed between two other layers with ordinary doping levels. The project is working on a zinc sulphide solar cell heavily doped with chromium, which theoretically can achieve a conversion efficiency of 47%.

There are materials that can make solar cells even more efficient, but they often contain substances that are toxic before being bound in the solar cells. The question is whether the industry, technologists, politicians, environmental organisations and society at large will accept solar cells that offer cheaper electricity but contain potentially hazardous substances.

PROJECTS
203503 Socially Robust Solar Cells (SoRoSol)
181886 Nanomaterials for 3rd Generation Solar Cells

Turid W. Reenaas of NTNU in the laboratory for thin-film deposition.

Thermoelectric materials
In a project headed by Johan Taftø, the University of Oslo's Department of Physics has built up national expertise in materials that produce electric current when their temperature changes. The researchers have also succeeded in creating an energy-efficient material.

Project: 181995 Thermoelectric materials; synthesis, electronic structure, functionality

Better fuel cells
In a project at the University of Oslo, researchers under project manager Anette Eleonora Gunnæs studied metal oxide interfaces in anodes for solid oxide fuel cells, and modelled cathodes using various techniques.

Project: 182065 Nano-ionics for energy technology (NANIONET) – Integrated theoretical and experimental analysis of surfaces and microstructures

New lithium batteries for vehicles
Researchers at the University of Oslo are using a method of stacking layers of atoms (atomic layer deposition) to develop improved, higher-efficiency lithium batteries. Thanks to the project, headed by Helmer Fjellvåg, the university is among the leaders in this technology.

Project: 178177 High-Power Solid-State Lithium Batteries

Helping to create far larger wind turbines

The longer the turbine blades, the more energy a wind turbine can generate. But how is it possible to make 100-metre-long blades that do not crack or hit their tower? Researchers in Porsgrunn are making headway.

Wind turbine blades are constructed of a thin, hard outer shell and a stiff, porous core which must maintain the blade's shape while ensuring stiffness. Ideally, the output of each wind turbine should be maximised using longer and longer blades. Doubling the blade length yields roughly four times the turbine output. Currently, the longest blades are 50 m in length; with new technology they may reach 100 m.

The stiffness-to-weight ratios of current materials, however, limit blade length. Long blades with the stiffness not to hit their tower are too heavy for a turbine atop a high tower.

In a project headed by Harald Jacobsen of the company Ineos, researchers are developing a PVC foam core which can make a turbine blade 30% lighter than current materials, without weakening its strength. The key lies in particles just 5-100 nm in size.

The foam's nano-sized particles strengthen the core while making it lighter. The challenge is to get the nanoparticles to distribute perfectly evenly throughout the PVC foam without clumping, while ensuring that the particles have solid contact with the PVC.

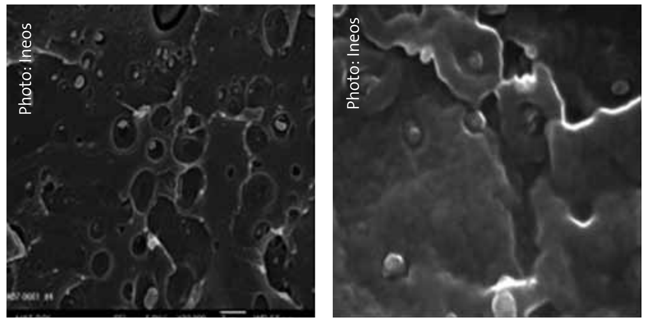
In a previous project, the researchers had determined how to modify nanoparticles of metal oxides or silica to distribute them evenly in the PVC foam to increase the material's impact strength without compromising its stiffness. This work led to a patent application for the method.

In the new project, the researchers have found several nanoparticles with the right surface properties for use in the PVC foam. SINTEF and the company Elkem Silicon Materials are participating in the project with nanoparticles based on proprietary technology.

PROJECTS

203505 High Strength PVC Foam for Wind Mill Applications

181785 Functionalised nanoparticles for use in PVC materials and processes



Electron microscope images of post-impact fracture surfaces of PVC foam. Left: Poor mechanical properties due to insufficient contact between nanoparticles and the foam material. Right: Good nanoparticle-to-foam contact results in vastly improved impact strength.

Hybrid battery 1

The company KeraNor studied how to use porous materials in lead batteries for hybrid vehicles. Headed by Bernt Thorstensen, the project yielded fundamental knowledge that is being carried over to a new project, Hybrid battery 2 (see below), as well as several EU projects.

Project: 176234 Development of ceramic bipolar battery plates using nanomaterials and nanotechnology

Hybrid battery 2

KeraNor is developing ceramic plates for lead batteries for hybrid vehicles. In a project headed by Bernt Thorstensen, researchers are developing stable, porous, ceramic plates of sufficient strength with the objective of creating a prototype plate.

Project: 193331 New materials for bipolar batteries

New production method for batteries

In a project headed by Lars Ole Valøen of the company Miljøbil Grenland, researchers are developing a production method for lithium ion batteries that lowers production costs while raising energy density – without compromising battery life or safety.

Project: 195491 New production process for lithium-based battery cells

Promising energy materials

Conducting oxides are a new group of materials that are raising hopes worldwide. Norwegian researchers are helping to develop both transparent conductors and proton conductors.

At the University of Oslo, Ola Nilsen and his colleagues found that they could use inexpensive chemicals to manufacture conducting zinc oxide as well as produce proton-conducting films with atomic layer deposition (ALD). The ALD technique enables scientists to design materials with atomic precision.

The University of Oslo and its partners are well into the three-year EMALD project, which concludes in 2013. Their objective is to develop transparent, conductive materials for solar cells and smart windows based on zinc oxide as well as proton-conducting materials based on heavier elements. The researchers hope their results will lead to new technology and a cost-competitive production method, which could yield more efficient solar cells, cheaper flat screens, and electrolytes for new types of low-temperature fuel cells.

PROJECTS

195233 Energy Materials by Atomic Layer Deposition (EMALD)

163574 Metal Organic Chemical Vapour Deposition (MOCVD) for synthesis of complex oxides

Colourful solar heating

Nanostructured surfaces will make modern solar collectors more efficient and more attractive.

Building-integrated solar collectors will soon be available in a range of colours, not only black such as those at this pilot facility in Oslo.

Aventa, an Oslo-based start-up, has been collaborating with industrial and research partners in Slovenia on developing a special paint coating using nanoparticles. The coating causes solar collectors to reflect less radiant heat in the infrared range, allowing more of the sun's energy to be converted into useful heat. A variety of colours that maintain high efficiency is helping to make solar collectors a more attractive option for building contractors and architects.

A MATERA project headed by Michaela Meir of the University of Oslo has also tested a durable, self-cleaning coating for the transparent, UV-absorbent surface of solar collectors. A nanostructured surface coating prevents dust and dirt from collecting and reducing the collector's efficiency.

PROJECT

189710 Multifunctional paint coatings for "all-polymeric" solar thermal collectors

New electrode materials in fuel cells

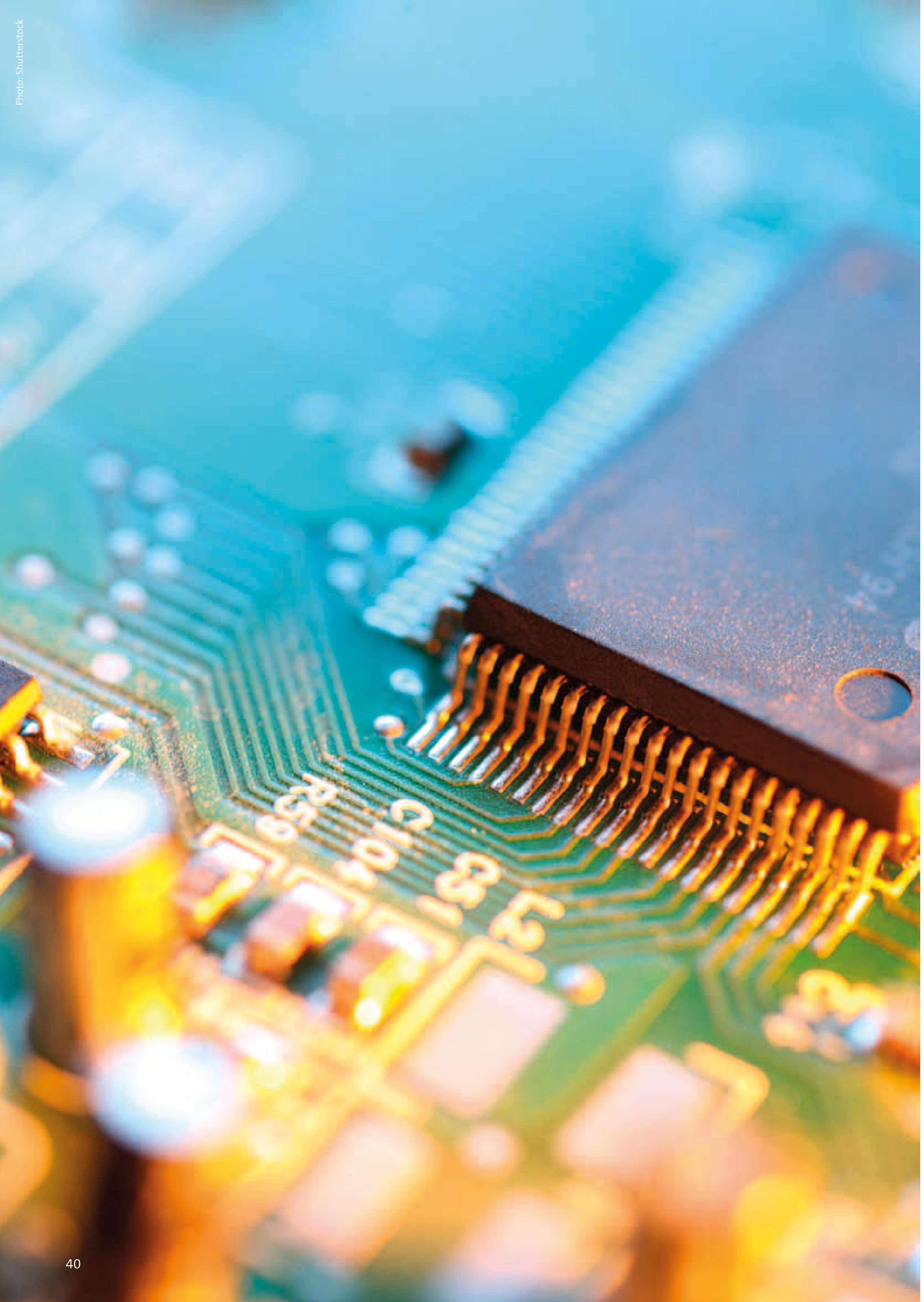
To design simpler, more stable fuel cells, researchers are seeking to lower operating temperatures to below 800ºC. The objective of a project headed by Arild Vik of the company Prototech is to develop new materials for the surface of fuel cell electrodes at lower production costs.

Project: 176214 Design and Production of Planar SOFCs from Nanoparticles with Emphasis on Support and Sealing

Catalysts for fuel cells

Tiny particles of noble metals covered with a layer of other elements' atoms can serve as effective catalysts for improving the performance of fuel cells. A project headed by Svein Sunde of NTNU studied how such particles can be used to improve methanol combustion.

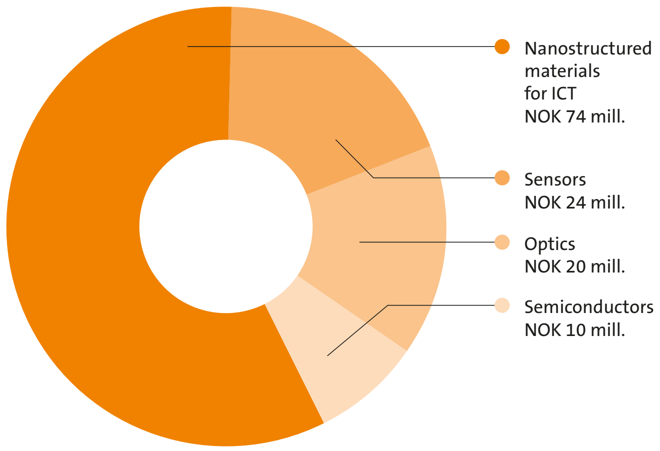
Project: 182044 Carbon-supported core-shell electrocatalysts for oxidation of small organic molecules



ICT and microtechnology

Research on ICT and microtechnology has been an area of focus since the programme started. The programme has funded projects ranging from basic research projects with very long-term objectives, to much more market-oriented projects. Some of the most important research questions revolved around microprocessors and sensors. ICT and microtechnology was the programme's second-largest thematic priority area, after Energy.

Project portfolio
From 2002-2011, the programme allocated a total of roughly NOK 130 million to 14 projects of relevance to ICT and microtechnology (approximately 18% of overall project funding). Of these, eight were researcher projects, five were innovation projects in the industrial sector, and one involved the establishment of a national graduate-level researcher school, the Norwegian PhD Network on Nanotechnology for Microsystems. The amount of funding awarded ranged from NOK 2 million to NOK 52 million for a nationally-coordinated project. That project allocation represented a full 40% of the funded awarded by the NANOMAT programme in this thematic priority area. The figure below shows the distribution of funding by technology area.



Selected trends – and challenges
The line separating micro- and nanoelectronics is in the process of disappearing. Miniaturisation, steadily increasing capacity and the demand for ever-faster processors are driving research and innovation activities forward. Nanotechnology holds great potential for realising new solutions and breakthroughs in information management and flow, through detection, storage and control. Microprocessors and sensors comprise two research topics of major interest.

Increasingly smaller sensors are being developed for environmental and process monitoring. These sensors are often used in continuous monitoring systems with stringent requirements for robustness and operational reliability. The same is true for sensors used for health care applications and in the health services. In terms of energy harvesting, new sensors are being developed that can help to harvest surplus energy, for example from personal vehicles. When it comes to data storage, nanotechnology has already demonstrated its full potential in today's advanced computers, whose storage capacity is growing steadily and which are getting faster and faster, and at the same time smaller and smaller. With the help of new nanotechnological solutions and advanced materials, this trend will continue.

Successful microparticles

Norwegian researchers are continually finding new ways to put Ugelstad particles to work. In the future these microscopic polymer particles could have important applications in consumer electronics.

The Skedsmo-based company Conpart has used Ugelstad particles in developing a materials technology in great demand by the international electronics industry. The company attributes much of its success to close collaboration with NTNU, where more basic research on microparticles has been carried out.

Results from the Hybrid project led to successfully commercialising microparticles for the liquid crystal display (LCD) industry. Conpart is set to repeat that success using the results from another project concluded in 2011.

Homogenous particles
In 2008 the first generation of particles used in manufacturing LCD screens was commercialised. The industry's exacting requirements meant that new material combinations had to be developed and characterised, while a method had to be found to exclude absolutely every single particle not of the prescribed size (roughly one in 1 000 particles) and guarantee 100-per-cent-homogenous polymer particles of a diameter as small as 2.5 microns. The particles' physical properties also needed to be customised and verified in cooperation with the Lillestrøm-based supplier Dynal, now called Life Technologies.

Conpart's customers add a conductive metal plating so the particles can be used as electrical interconnectors. Today these particles are found in many LCD screens.

In the most recent project, headed by Helge Kristiansen, Conpart is collaborating with SINTEF and the company Microbeads to develop far larger particles (700 microns) as a basis for new, environment-friendly, flexible solder balls. Their objective is to develop a product that will replace conventional solder balls (which are typically made of tin or copper) with polymer particles that are plated with copper and then covered with an alloy material to impart the physical properties needed for the soldering process.

All-important funding
Conpart is receiving funding from multiple Research Council programmes to develop and commercialise these products. Founder and CEO Tom Ove Grønlund emphasises that this funding is critical for enabling Conpart and its many partners to develop successful products for the electronics industry.

PROJECTS

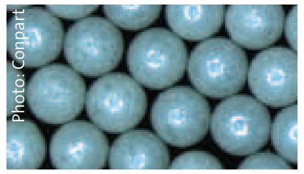
181817 Manufacturing and application of metal coated polymer particles as BGA/CSP balls in electronic interconnect

176225 Hybrid particles: Design, synthesis and characterisation

Affiliated projects at NTNU:

169737 Nanostructured Polymer and Composite Particles: Mechanical Properties

187269 From Molecular Structures to Mechanical Properties: Multiscale Modelling for Ugelstad Particles (MS2MP)



Conpart collaborates with several major players in the international electronics industry to develop more efficient, environment-friendly soldering methods based on Ugelstad particles.

Harvesting energy from vibrations

Batteries are impractical in many settings, particularly in small sensors in inaccessible places. In the SensoNor project, headed by Terje Kvisterøy, researchers developed microenergy harvesters that require no external power source and are integrated into sensors for measuring vehicle tyre pressure.

Project: 176485 Nanomaterials for Harvesting Microenergy

New nanostructures in semiconductors

A deeper understanding of nanostructures in semiconductors may pave the way for new applications in electronics and optics. Researchers in a project headed by Andrej Kuznetsov of the University of Oslo discovered new properties in semiconductors and produced nanocrystals of silicon and germanium. One application area is solar cells.

Project: 158549 Semiconductor nanostructure research

Production of new semiconductor material

Monocrystalline zinc oxide is a promising new semiconductor material. Researchers in a project headed by Bengt Gunnar Svensson of the University of Oslo have studied how to use ion beam radiation to modify the electric, optical and magnetic properties of thin films for applications such as solar cells.

Project: 182018 Nanostructuring of novel semiconductors by ion beams

Lens for mobile-phone cameras

Copying the workings of the human eye, mobile-phone cameras may soon be equipped with a built-in, auto-focusing lens with no moving parts.

When the eye focuses at close range, its muscles contract slightly to adjust the lens' curvature. The muscles relax again to focus the eye at a distance. Researchers at the Horten-based company PoLight have borrowed nature's design; a polymer plays the role of the lens, while a piezoelectric film represents the muscles. (Piezoelectric materials contract when subjected to an electrical current.)

With no moving parts, the lens needs just one millisecond to focus – far faster than the 10-50 ms required by other lenses.

PoLight's Jon Herman Ulvensøen headed the TLENS project that laid the foundation for what will hopefully find commercial success. Back in 2006, SINTEF and the company Ignis Photonyx saw great promise in tunable lenses. The following year more investors came on board, and the company was renamed PoLight. Its technology was demonstrated in 2008, and in the course of 2012 the company plans to begin supplying the lens in volume.

PROJECTS

176390 TLENS (Tunable lens) – A tunable polymer-based auto-focus lens

169595 Functional optical and electric polymer films

Jon Herman Ulvensøen of PoLight with the prototype for a mobile-phone camera lens.

From lasers to solar cells

Researchers at NTNU had set their sights on developing nanowire lasers – but instead found a bright way towards more efficient solar cells.

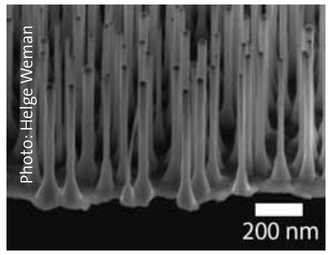
Four years into the NTNU nanolaser project, the researchers found their objective more elusive than they had originally foreseen. Undeterred, they applied their project results to two promising spin-off projects to develop higher-efficiency solar cells.

Now, the original project, headed by NTNU's Helge Weman, is well on its way to finding the right materials and structures for nanolasers.

The research team has studied how to control the growth of nanowires in cubic and hexagonal structures, whose different optical and electrical properties are combinable to produce new components with entirely new characteristics.

PROJECT

182091 Modelling and Fabrication of Nanowire lasers



Carbon nanowires growing on nano-sized gold particles.

Advanced production methods

In a project carried out at the University of Oslo's Centre for Materials Science and Nanotechnology, project manager Henrik Ræder and his team built up expertise in producing nanoparticles of semiconductors as well as integrating and producing silicon and piezoelectric films.

Project: 153864 Material science and nanotechnology at the NMC-MRL; functional oxides and oxide-imbedded nanostructures

Tunable optical filters

The opening of the University of Oslo's MiNaLab laboratory sparked a project to study how semiconductor materials could also be applied in optics. The Nanophot project, headed by Aasmund Sudbø of the University Graduate Center at Kjeller (UNIK), culminated in a patent application and industrial utilisation.

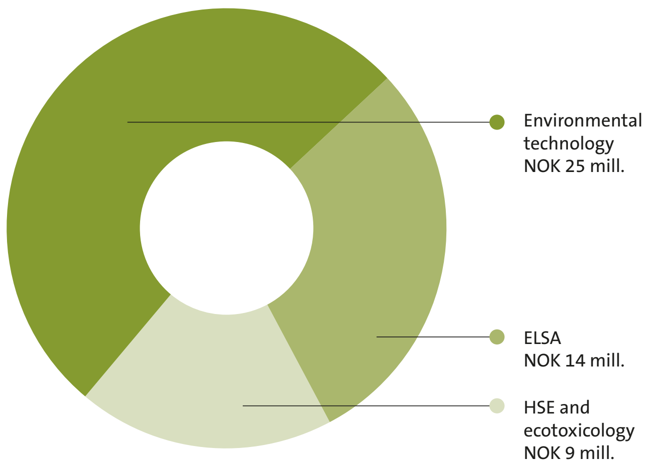
Project: 163549 Nanostructures for optics

Photo: Colourbox

The environment and responsible technological development

Focus on issues relating to health, safety and environment (HSE) and the ethical, legal and social aspects (ELSA) of technology development grew in the course of the programme period. While the NANOMAT programme was evolving from a "basic research programme" to a policy-oriented Large-scale Programme, HSE and ELSA were being given a more prominent place on the research policy agenda and thus became a priority area under the programme.

Project portfolio
From 2002-2011, a total of approximately NOK 48 million was allocated to 13 projects in this area (roughly 6% of overall project funding). Some NOK 23 million of this amount was allocated to ELSA-related projects (including integrated research projects on consumer perspectives) and HSE/ecotoxicology projects. NOK 25 million was allocated to environmental technology projects for developing new technological solutions to reduce negative environmental impacts and/or promote the sustainable use of natural resources. The amount of funding awarded ranged from NOK 14 000 for network-building measures to NOK 6 million for a single researcher project. The figure below shows the distribution of funding by area.



Selected trends – and challenges
The field of environmental technology seeks to promote the sustainable use of natural resources and to create new solutions that have less environmental impact. Norwegian research groups are in an excellent position to contribute to advancements in a number of areas. New insight into catalysts at the nanoscale may lead to more effective processes for producing biofuels and recycling waste. In the transport sector, there is major potential for reducing fuel consumption by using lighter, stronger, nano-based materials. Ensuring access to clean water is a pressing global challenge, and the development of new, nano-based membrane technology in this area holds promise for Norwegian commercial players and researchers.

It is vital to maintain focus on socially responsible technology development. The lack of knowledge about the potential effects of nanomaterials on humans and the environment is problematic, and there is a need for better analytical methods for characterising nanomaterials.

Socially responsible technology development requires productive cooperation between researchers studying ELSA-related topics and researchers studying HSE, risk and ecotoxicology-related topics. This in turn will require new forms of interdisciplinary cooperation as well as social dialogue involving open, wide-ranging discussion of research-related issues.

Knowledge about nanotechnologies will provide decision-makers with a better basis for designing policy and regulations that give adequate consideration to both opportunities and threats and will ensure that value-based decisions relating to technology development reflect the public interest.

Debate on nanotechnology's development goes public

The views of consumers, politicians and everyday citizens are all valuable in the debate on how nanotechnology should be developed and utilised.

How should political, regulatory and scientific policy decisions be taken when it is reasonable to assume that the technology will have unforeseen and surprising impacts down the road? A three-year project headed by the University of Bergen's Roger Strand took an interdisciplinary approach to the question, studying the uncertainties and complexities in an integrated perspective.

The project encompassed studies of the use of photos and graphics in presentations and communication materials on nanotechnology, conditions for effective social dialogue, and ethical and regulatory aspects of nanoscientists' social responsibility.

The project also featured an analysis of various ideological discourses on nanotechnology and nature, which culminated in an article published in the prestigious journal *Nature Nanotechnology*.

Cultivated consumer involvement

A small-scale project in 2006 had major ripple effects in terms of openness surrounding nanotechnology in Norway. Up to that point, scientists and industry had largely defined the agenda, pointing out all the benefits of nanotechnology. A project headed by Eivind Stø of Norway's National Institute for Consumer Research (SIFO) drew consumers, politicians and special interest organisations into the issue of who has a responsibility to be precautionary.

In the course of the project period, nanotechnology emerged from the confines of universities and laboratories and out to companies and eventually the consumer market.

The project researchers interviewed an array of stakeholders in society to find out how concerned they were that the precautionary principle be used when developing new technology. The study revealed that the level of knowledge surrounding this issue varied greatly, but the study itself raised the level of awareness and understanding of nanotechnology.

The project resulted in Norway's entrance into a network of comparable research groups in other countries, and a platform was established for the Norwegian research community to participate in EU programmes. Another result was the appointment of Norway's National Institute for Consumer Research (SIFO) as coordinator for an EU project.

PROJECTS

171 838 Interdisciplinary Studies of Ethical and Societal Implications of Nanotechnology

171 842 The precautionary principle in nanotechnology: Who should be precautionary?

Follow-up project

182043 Governance of the precautionary principle and the nano-consumer: A comparison of ethical aspects in nano-products in Norway and the UK

For her research on nanotechnology and ethics, Kamilla Kjølberg of the University of Bergen received the Meltzer Prize for Young Researchers, presented here by the university's rector, Sigmund Grønmo.

Network for HSE and ELSA

SafeNano Norway is a national network covering all areas of health, safety and environment (HSE) as well as the ethical, legal and social aspects (ELSA) of nanotechnology. Most of Norway's major research players as well as some industrial companies participate in the network.

Project: 203559 National network initiative in the area of HSE and ELSA aspects of nanomaterials

Building trust when developing technology

In a project headed by NTNU's Bjørn Myskja, researchers studied how risk analyses are handled in early phases of technology projects. The project discussed risk, trust and the benefits of nanotechnology.

Project: 182046 NANOTRUST: Ethical conditions for a socially robust use of nanobiotechnology in aquaculture

Society and new solar cells

In an integrated project – a new type of project at the Research Council – the technological development of third-generation solar cells will go hand-in-hand with social science research in order to include special interest groups' viewpoints on the development process of this technology.

Project: 203503 Socially Robust Solar Cells (SoRoSol)

Nanotechnology as an environmental problem – and a solution

Certain nanoparticles can represent a health risk to living organisms, while other nano-scaled materials may offer sound solutions to other environmental problems.

Metals such as silver, cobalt and cerium are toxic in certain chemical compounds. In a project headed by Erik Joner of Bioforsk, researchers have found that also the nanoparticles of these metals can have adverse effects on both health and the environment when released into nature. Silver, the most common of the three, is used as an anti-bacterial coating in products such as washing machines. Silver has been found in fish, earthworms, and other organisms.

Membrane of cellulose fibrils

Nanostructured materials can also be beneficial for the environment. With a number of consecutive projects over the course of several years, the Paper and Fibre Research Institute (PFI) has become a global frontrunner in creating exciting new characteristics of cellulose. In the most recent project, headed by Kristin Syverud, PFI researchers have developed methods for using cellulose fibrils to make the properties of fluids more environment-friendly.

In collaboration with the global company AkzoNobel, PFI produced microfibrillated cellulose that can stabilise the fine water droplets in diesel fuel. In the same project, PFI worked with Norwegian paint producer Jotun on using this cellulose product as an environment-friendly additive in paint. The cellulose fibrils form a thin coating on the surface of the microscopic water droplets in diesel, and similarly on the oil droplets in paint. This helps to produce the most stable and homogeneous mixture possible to prevent the fluids from separating.

More durable paint

In an earlier project, Jotun collaborated with SINTEF on developing surface-modified silica particles that help to reduce the need for paint thinners that are hazardous to health. In a project headed by Tina Helland of Jotun, researchers studied how these particles can improve epoxy-based paint's durability to light and chemical exposure.

PROJECTS

182069 Environmental fate and ecotoxicity of manufactured nanoparticles
181808 Nanosized cellulose fibrils as stabilizers of emulsions
187250 Environment-friendly binders and paint systems based on modified silica nanoparticles
176216 Silica nanoparticle binding technology
163582 Development of new bio based materials using nanotechnology

Award-winning researchers

Ferdinand Männle and Christian Simon won the SINTEF Award for Outstanding Research for their contribution towards more environment-friendly house paint.

Plastic membranes to separate out CO_2

With the right plastic molecules (polymers), a membrane can be permeable to certain gases while impermeable to others, and can be used, for example, to separate CO_2 from hydrogen gas. In a project headed by SINTEF's Jon Samseth, three different membranes with promising properties were developed.

Project: 163530 Design and Development of Robust Nanostructured Polymer and Nanocomposite Membranes for Selective Acid-Gas Separation

Design of low-toxicity nanofibres

When hydrogen is produced from natural gas, one by-product is nano-sized carbon fibres. In a project headed by Ellen Katrine Jensen of the company Elkem, researchers studied the properties of such carbon fibres produced under various conditions, and carried out toxicological tests on mice and cells.

Project: 176425 Carbon fibres and health – design of nanofibres with low toxicity

Microfibrillated cellulose is proving to have a great many exciting applications as a component in other materials.

Photo: Shutterstock

Photo: Shutterstock

Health

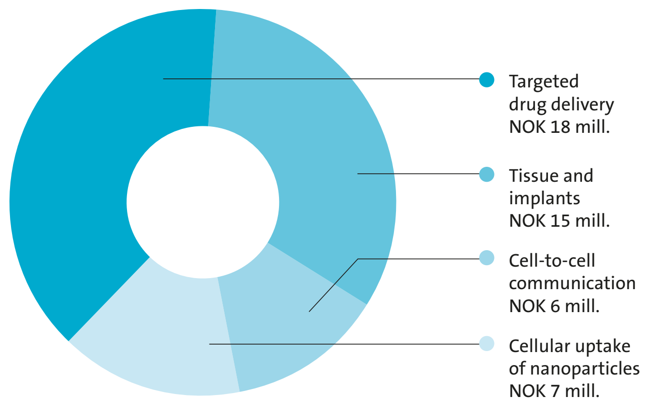
From the time it was established in 2002, the NANOMAT programme has placed focus on research within the area of health, most prominently in the work programme for the 2007-2011 period. The programme has funded projects on targeted drug delivery, personalised medicine, and engineering of tissue/implants with improved biological function. The programme has also funded more basic research-oriented projects on cell-to-cell communication and cellular uptake of nanoparticles – research which is of vital importance to the use of nanostructures in health-related applications.

Project portfolio

From 2002-2011, the programme allocated a total of well over NOK 40 million to 13 projects of relevance to health (approximately 7% of overall project funding). The amount of project funding awarded ranged from NOK 8 million to NOK 80 000 for national networks. This area of research was underfunded in the latter years of the programme. Growth in the programme budget was directed towards the area of renewable energy and came from extra allocations resulting from the broad-based political agreement on climate policy achieved in the Storting in 2008. The figure below shows the distribution of funding by research area.

Selected trends – and challenges

The effort to maintain a sustainable health care system poses huge challenges to Norway. This is due in part to the trend towards a rising number of elderly and the diseases and care needs that accompany this. Patient needs are therefore a driver of nanotechnological health research. This type of research is interdisciplinary and is characterised by activities that seek to expand the understanding of biological principles to incorporate new knowledge about the properties of things at the nanoscale and the application of ICT to control complex processes.



There was intensive research activity in the area of targeted drug delivery, where the aim is to impart medicines with stealth properties and targeted functions. In this manner side-effects can be avoided and medicines can be tailored to the needs of the individual. Comprehensive research was also carried out to find new ways of "growing" tissue and constructing implants that can replace damaged skin, defective organs and worn-out joints (regenerative medicine). A third area of focus comprised biosensors and other devices for early diagnosis and disease monitoring, also in conjunction with therapy (theranostics).

Nanomedicine touches on issues of relevance to both the individual and society at large, and the doctor-patient relationship. For example, there is a gap between access to diagnosis and genuine treatment possibilities and close(r) patient monitoring. The unique properties of nano-scale materials also pose uncertainties in terms of where and how these materials are taken up by the body and their effects on vital organs. Only when these questions are answered will we be able to apply nanomedicine on a wide scale.

There is now an array of exciting start-up companies in the nanohealth segment in Norway. The challenge here will be to further develop these companies into industry players of adequate size and reach that can contribute to value creation in Norway.

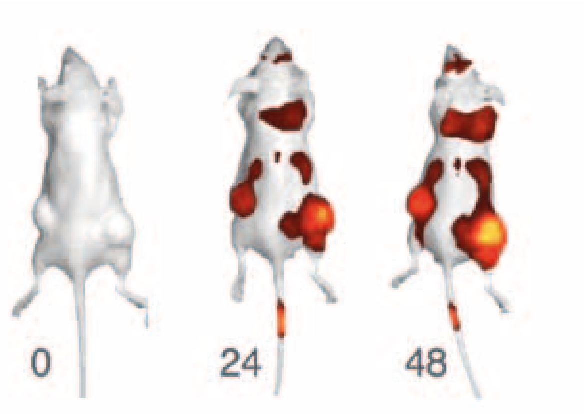
Ultrasound to release targeted cancer drugs

Soon, cancer drugs will be targeting cancerous cells directly and sparing healthy cells. The Norwegian company Epitarget has caught the international eye and is in contact with major pharmaceutical firms.

Many researchers are seeking ways to deliver drugs to cancer cells using liposomes (fatty bubbles) which are transported by the blood and attach to cancerous cells. The challenge lies in getting the drug from the liposome into the cancerous cell. Esben A. Nilssen and Sigrid Fossheim hit upon the idea of using ultrasound to break open the liposomes and cell walls to allow the drug to enter.

Industry-initiated project
After four years of research, they have developed a method and have demonstrated it in multiple animal trials. Now Epitarget must decide whether to license the technology to a major pharmaceutical company or develop the delivery method and cancer drug themselves.

Illustration: Epitarget



The liposomes are shown accumulating in cancerous tumours in a mouse over a 48-hour period. Targeted ultrasound opens the liposomes and releases the cytotoxic drug.

Epitarget's story is not the typical tale of a researcher from a research institution founding a company based on many years' work. In this case, it was a small company that launched a purely industrial project.

International collaborators
In 2007 the privately owned company was renamed Epitarget and was streamlined to focus on developing this concept. Collaboration was established with France's National Institute of Health and Medical Research (INSERM) in Lyon.

Epitarget receives funding from the NANOMAT programme and the French Norwegian Foundation (FNS), which promotes long-lasting French-Norwegian cooperation through the financing of joint R&D projects involving both industry and research institutes/universities. Together with its French partners, Epitarget recently secured funding from the Eurostars programme, which promotes international research collaboration led by R&D-intensive SMEs.

Epitarget's collaborative research has resulted in eight scientific articles and three Ph.D. degrees, one of which was completed with support from the Research Council's Industrial Ph.D. scheme. The method developed is awaiting patent in several countries.

PROJECTS

181779 Development of novel sonosensitive liposomes for targeted ultrasound mediated drug delivery – a new paradigm within cancer therapy

179253 Effect of ultrasound dosimetry on drug release from liposomes-implications for development of novel acoustically sensitive liposomes

Controlled drug delivery
Medicines encapsulated in a gel can be released into the body when triggered by temperature, pH level or light. A project headed by the University of Oslo's Bo Nystrøm has provided new insight into the functions of biomolecules in the gel.

Project: 158550 Functional Biomacromolecules for Application in Controlled Drug Delivery

Customising nanocapsules
In a project carried out at SINTEF under project manager Christian R. Simon, researchers developed methods to produce stable drug capsules measuring just 50 and 250 nm in diameter. The capsule surfaces can be modified to suit a particular purpose.

Project: 179590 Multifunctional Particulate Systems for Nanomedicine

Nanomedicine network
To promote the participation of Norwegian research players in the EU's Seventh Framework Programme under the theme Nanosciences, Nanotechnologies, Materials and New Production Technologies (NMP), SINTEF established a Norwegian nanomedicine-related network in 2007. It provides meeting places where members can obtain information about relevant research programmes.

Project: 182280 National initiative for a nanomedicine network

Towards replacement parts for humans

Nanotechnology is yielding new, safer materials for implants, as well as opening up new possibilities in cancer research and tissue engineering.

Titanium, thanks to its excellent biocompatibility, is the preferred metal for prostheses and implants. An alloy with titanium is strong and ductile (easily moulded). But if the titanium begins to corrode, or if tiny particles detach from the alloy, this can be toxic, even carcinogenic. In a project headed by John Walmsley of SINTEF, researchers are developing a method to produce pure titanium of a quality that can be shaped for use in prostheses and implants.

Stronger than pure metal
Pounding titanium reduces the size of its constituent grains to the nanoscale. Then, heating the titanium gives it far better strength and biocompatibility than when unprocessed; it becomes nearly as strong as an alloy. But this remains a costly process.

SINTEF and NTNU are building up a specialist community with substantial expertise in this area that is attracting notice from international research groups.

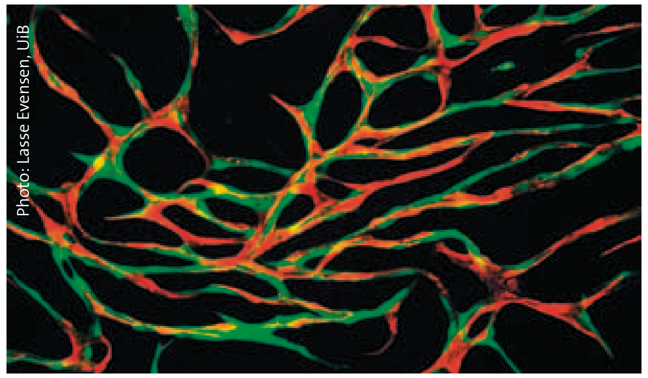
Mimicking bodily processes
In a project headed by the University of Bergen's James Lorens, researchers have found a way to induce cells to develop blood vessels in engineered tissue. In principle, cells "know" their intended function well, but the engineered tissue must provide the right conditions for cell development to run its natural course and form healthy, functional blood vessels. The researchers have found a specific nanostructured surface that sends the cells the correct signals so they develop as desired.

Hope for new cancer treatment?
One of the sensational findings is that the researchers can use this new method not only to develop new, healthy tissue but also to recreate diseased tissue – cancerous tumours. This may lead to new knowledge about the progression of tumours and their interaction with blood vessels, and in turn to the development of new drugs and therapies to fight cancer.

PROJECTS

182000 Pure and ultra-fine grained Titanium for biomedical applications

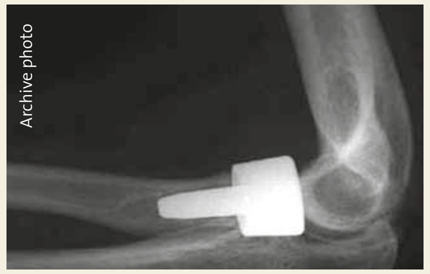
182061 Nanostructured biomaterials for improved vascularization in tissue engineering



Researchers at the University of Bergen have successfully grown blood vessels in a cell model that mimics the way the body forms blood vessels.

Plaster that stops the bleeding
By adding a layer of nanofibres to plaster materials, the company Snøgg performed introductory studies on plasters with blood-stopping properties. The nanofibres are so small that they come into direct contact with the individual blood cells.

Project: 182294 Innovative nanotechnology-based depot plaster for wound healing and medical treatment



Pure titanium is ideal for prostheses but difficult to shape. Researchers at SINTEF have made advances in titanium processing.

Cells use nanotubes to send signals

A dramatic discovery by researchers in Bergen has revealed that most of the body's cells communicate using electrical signals. The discovery may help to explain how cells cooperate to develop tissue in the embryo and how wounds heal.

For nearly ten years, researchers have known that cells can "grow" ultra-thin tubes called tunnelling nanotubes (TNTs) between one another. These nanotubes – the length of two to three cells and just 50-200 nm in diameter – are connections that develop between nearly all cell types to form a communication channel different from any previously known mechanisms.

In 2010, the University of Bergen's Xiang Wang and Hans-Hermann Gerdes discovered that in addition, electrical signals pass through these nanotubes, sending information from one cell to another at high speed.

The findings have attracted attention and were prominently profiled in *Nature News* in autumn 2011.

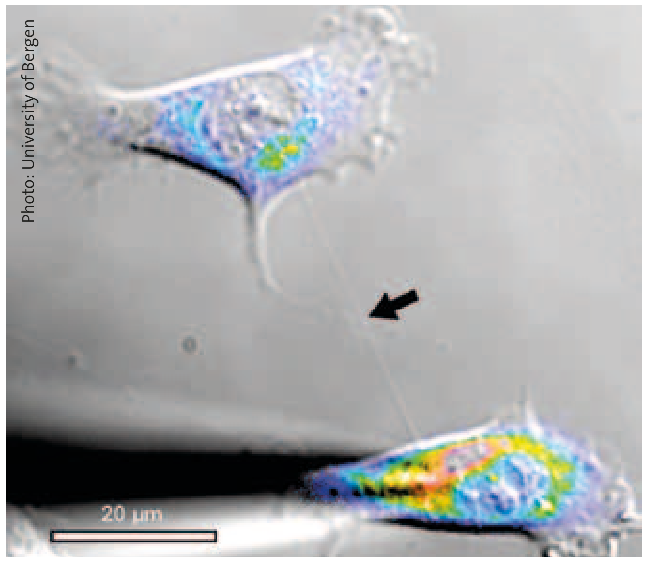
Intercellular nanotubes are difficult to observe; once they establish contact, they disappear after only a few minutes. So the Bergen-based researchers developed advanced equipment to manipulate the cells and raise the likelihood of finding and filming nanotubes.

Now the neuroscientists are seeking answers as to *why* the cells send signals to each other. The signals may, for example, explain how cells are coordinated during embryo growth, when cells travel long distances yet demonstrate a kind of collective behaviour, moving together much like a flock of birds can. Nanotubes may also be involved in steering cell movement towards a wound in order to heal it. If these same signalling mechanisms prove to be present in human brain cells, it could add a new dimension to understanding how the brain functions. According to the *Nature News* article, the neuroscientists see this research as an opportunity to formulate better explanations for phenomena related to consciousness and electrical connections in the brain.

PROJECTS

182093 Towards the mechanism of formation and function of tunneling nanotubes

172646 Characterization of nanotubular networks on cell adhesive micro- and nano-patterned surfaces



Here a cell has coupled with another cell by growing a long nanotube which enables it to pass electrical signals.

Nanotubes were profiled in the 30 November 2011 issue of *Nature News*.

Nanoparticles can hinder intracellular transport

New medicines containing nanoparticles are proven to have clear curative value, but complications can sometimes arise. Researchers at the Norwegian Radium Hospital in Oslo have shown how nanoparticles can interfere with the transport of vital substances in cells.

Nanotechnology enables scientists to customise medicines and the vehicles that deliver them to where the body needs them. Numerous animal trials have shown some promising results. But the effect of nanoparticles on cell function – once the drug has done its job – is not yet well understood.

Tore-Geir Iversen of Oslo University Hospital/Norwegian Radium Hospital and his colleagues began by posing some very fundamental questions: What happens once the nanoparticles enter the cells? Do they accumulate in the cell or are they excreted? Is their effect toxic to cells? The project received funding under two of the Research Council's Large-scale Programmes: Functional Genomics in Norway (FUGE) and the NANOMAT programme.

Researchers working on the project studied nanoparticles 30-100 nm in diameter, a common and practical size for delivering medicines and DNA into cells.

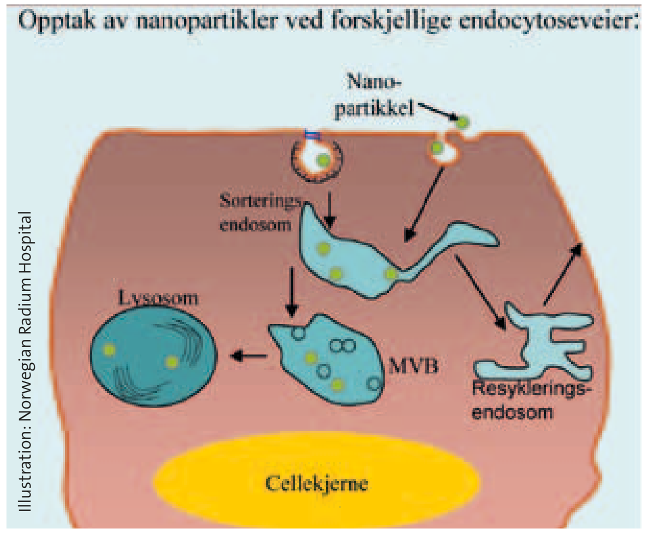
After four years of experimentation, the researchers are zeroing in on how nanoparticles behave in cells. Dr Iversen's group is the first to show that uptake and accumulation of nanoparticles in cells can disrupt important intracellular transport pathways.

Trials showed that a protein that transports iron into a cell is taken up in the usual way even when bound to a nanoparticle. However, while 99% of a protein not bound to a nanoparticle will make its way out of the cell and can be recycled, a nanoparticle-bound protein remains in the cell. The likely explanation is that the protein has to enter a cell through very thin tubular structures. Nanoparticles of a larger size either cannot enter the tubular structures or they lodge inside and plug it up. This is critical knowledge when it comes to designing particles for medical applications.

PROJECTS

172663 Entry of nanoparticles into cells: Characterization of nanoparticles as tools to study endyotic pathways and intracellular transport

182058 Uptake and toxicity of quantum dots in cancer cells



Nanoparticles are taken up in the body's cells via various transport pathways.

Photo: Anne Ditlefsen, Research Council of Norway

Photo: Shutterstock

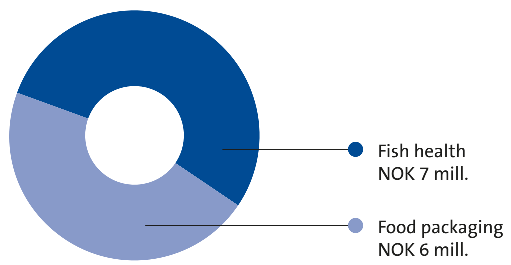
Oceans and food

Oceans and food comprised a separate thematic priority area in the work programme for the 2007-2011 period. For the most part funding has been allocated to food-related projects, particularly on food and packaging; there is therefore greater focus on these in this report.

Project portfolio
From 2002-2011, the programme allocated a total of NOK 13 million to three projects of relevance to oceans and food (approximately 2% of total project funding). The amount of project funding awarded ranged from NOK 1.6 million to NOK 8.8 million. Food-related research was underfunded in the latter years of the programme. Growth in the programme budget was directed towards the area of renewable energy and came from extra allocations resulting from the broad-based political agreement on climate policy achieved in the Storting in 2008. The figure below shows the distribution of funding by research area.

Selected trends – and challenges
Effective production and distribution of food is essential to global development and reduction of inequalities. When it comes to animal health and disease control, nanotechnology can be used to develop new solutions for vaccination and drug delivery.

Food traceability is a growing area of focus. With the help of nanotechnology, sensors can be inserted into food products to make it possible to track a product all the way back to its origin, i.e. the animal or field from which it came.



The concept of the bioeconomy entails greater focus on production of new types of biomass for use as food, animal feed, industrial by-products and energy. A key component of the bioeconomy is the full utilisation of resources at every stage of the biological cycle. The destruction of "spoiled" food is a major societal problem. Research is being conducted on nanomaterials with packaging properties that will improve the shelf life of food products and facilitate their transport over long distances and under varying temperature conditions.

Another important research area is functional food, which involves adding a dimension to food that goes beyond satiation. With the help of nanotechnology, foods can be developed to "smuggle" nutrients into the body, and the nutritional content of the food can be tailored to the individual's taste and health status. There is particular focus on reducing the fat and sugar content of food products, without adversely affecting their flavour.

There is tremendous growth potential in aquaculture production, but research is needed to ensure that production remains sustainable. Nanotechnology and advanced materials in combination with biotechnology have a role to play in the development of new technological solutions. Important focus areas here include utilising existing biomass as feed, improving fish health and finding new types of materials for net-cages and processing equipment.

There is uncertainty attached to the uptake of nanomaterials in foodstuffs and thus into the body. Direct contact between nanomaterials-based packaging and the food itself may, for example, be problematic. It is essential that research in this area food addresses such issues.

Nano-delivered vaccine could save billions

Each year the Norwegian aquaculture industry loses a billion crowns due to the infectious pancreatic necrosis (IPN) virus. Now researchers are turning to nanoparticles to develop a more effective vaccination method.

In Norway alone, the IPN virus causes annual losses in seawater and freshwater production totalling around NOK 1 billion. Improving the efficacy of IPN vaccines – while avoiding serious side effects on Atlantic salmon and other salmonids – has been a high priority.

In a project headed by Øystein Evensen of the Norwegian School of Veterinary Science, researchers have developed a promising particle-based vaccine. The vaccine's antigen is transported into the body with the aid of nanoparticles.

Fish in particular, but also other species, react better immunologically to vaccine antigens in particle form than in fluid form. Since the nanoparticles are uniform in size and shape, the fish immune system recognises the vaccine better.

The particles themselves – although tiny at just over 100 nm – are not so small as to pose a danger to the fish or the environment. Constructed of sugars, the particles are immediately broken down in the body once their job is done.

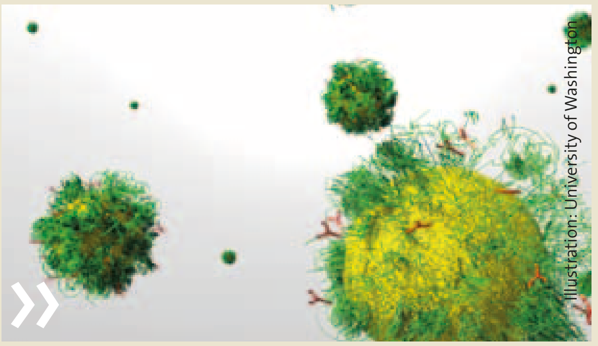


Illustration: University of Washington

Fish vaccine

Researchers at the Norwegian School of Veterinary Science have developed a fish vaccine that uses nanoparticles to deliver its antigens.

PROJECT

182035 Immunisation strategies against viral pathogens of Atlantic salmon


Photo: seafood.no

Packaging for a better environment

New research provides the basis for developing more environment-friendly packaging for the food industry, among others.

Over 800 000 tonnes of food is thrown out in Norway each year. Meanwhile, spoiled food causes several thousand acute cases of food poisoning annually. Better packaging barriers would greatly reduce these figures. Industry and the research community are working to develop packaging products with equal or superior food-preserving properties than current packaging – yet which are more climate- and environment-friendly and no more costly.

SINTEF's Bjørn Steinar Tanem has served as project manager for two projects under the NANOMAT programme in which researchers developed sustainable nanomaterials that simplify certain packaging applications. The nanomaterials used are microfibrillated cellulose (MFC) from the Paper and Fibre Research Institute and an organic/inorganic hybrid polymer that SINTEF has registered under the trademark FunzioNano™.

The project's researchers have also developed a laboratory prototype for drink-carton packaging that reduces the number of layers from six to four.

Knowledge gained from the project has been carried over to the EU project NanoBarrier.


Photo: Atle Abelsen

Improved packaging

Improved packaging is one key to reducing not only food waste but also the incidence of food poisoning.

PROJECTS

169735 Development of customized barrier packaging by novel nanoparticle technology (Phase 1)

176212 New innovative barrier solutions for targeted fresh food packaging applications (Phase 2)


Photo: Shutterstock

List of NANOMAT projects

No.	Project title	From year	To year
157327	Equipment for combinatorial chemistry (FUNMAT consortium)	2002	2003
157326	Wet-chemical equipment (FUNMAT consortium)	2002	2003
157325	Equipment procurement (spin-coater, wet-chemical equipment, FUNMAT consortium)	2002	2005
157324	Spin-coater (equipment, FUNMAT consortium)	2002	2003
157323	Equipment for spray pyrolysis (FUNMAT consortium)	2002	2003
157322	LPE digel (equipment, FUNMAT consortium)	2002	2003
157321	ALCVD reactor (equipment, FUNMAT consortium)	2002	2005
157320	Equipment for electron beam lithography (equipment, FUNMAT consortium)	2002	2003
157318	Equipment for electron beam lithography (equipment, FUNMAT consortium)	2002	2004
157317	PCT equipment (FUNMAT consortium)	2002	2002
156746	Research stays abroad, FUNMAT consortium	2002	2007
158541	Nanostructured Soft and Complex Materials	2003	2009
153869	Hybrid Materials	2003	2007
153864	Material science and nanotechnology at the NMC-MRL functional oxides and oxide-imbedded nanostructures	2003	2007
158552	New Catalysts for Activation and Functionalization of Alkanes	2003	2007
158547	Quantum Transport in Nanoscale Systems	2003	2007
158538	Molecular modeling in nanotechnology	2003	2007
158534	Bio polymer based nanocomposites Processing and Relationship between Structure and Properties	2003	2007
158518	Nationally Coordinated Project in Oxides for Future Information and Communication Technology	2003	2009
158516	Nationally Coordinated Projects in Materials for Hydrogen Technology	2003	2009
158545	Modification of Properties of Aluminium Alloys by Surface Segregation of Nanoscale Trace Element Particles	2003	2007
158519	Preparation of new chemically nanostructured materials via exfoliation of layered materials	2003	2008
158549	Semiconductor nanostructure research at the Norwegian Microtechnology Centers Microtechnology Research Laboratory	2003	2007
158558	Using Nanoscale objects to Modify Structural Development at Different Length Scales	2003	2008
158550	Functional Biomacromolecules for Application in Controlled Drug Delivery	2003	2006
158521	FUNMAT – Infrastructure and nationally coordinated network of functional materiails and nanotechnology	2003	2004
158517	Functional Oxides for Energy Technology	2003	2008
158554	Exclusion statistics transformation and application to mesoscopic systems	2004	2008
163574	Metal Organic Chemical Vapour Deposition (MOCVD) for synthesis of complex oxides	2004	2011
163556	The nature and origin of natural magnetic nanoscale materials	2004	2007
163582	Development of new bio based materials using nanotechnology	2004	2007
163563	New powder neutron diffractometer – PUS 2	2004	2010
163558	Structure and Dynamics of Soft and Complex Nanomaterials	2004	2008
163529	Dendritic nanoporous materials with multifunctionality	2004	2007
163549	Nanostructures for optics	2004	2010
163565	Novel nanostructured materials by chemical methods	2004	2009
163560	Pulsed Laser Deposition Laboratory	2004	2007
163530	Design and Development of Robust Nanostructured Polymer and Nanocomposite Membranes for Selective Acid-Gas Separation	2004	2010
163570	Nanocarbon for novel composites and functional materials	2004	2006
169676	Funding for Swiss-Norwegian Beam Lines (SNBL) at the ESRF, Grenoble, France	2005	2011

No.	Project title	From year	To year
163550	Theoretical modeling of nanomaterials for hydrogen storage applications	2005	2008
169656	High efficiency Si-based solar cells employing nanostructured layers	2005	2009
169595	Functional optical and electric polymer films	2005	2008
163576	Application of STM techniques for the study of electrocatalytic systems	2005	2008
169735	Development of customized barrier packaging by novel nanoparticle technology	2005	2006
169704	Nano-magnetoelectronic-mechanical systems	2005	2005
172646	Characterization of nanotubular networks on cell adhesive micro- and nano-patterned surfaces	2005	2010
169738	Delivery of liposome-membrane associated anticancer agents to solid tumors exemplified by Camptothecin liposomes	2005	2007
179109	Japan-Norway technology cooperation, Kyoto International Forum for Environment and Energy (KIFEE)	2006	2006
175760	Kyoto International Forum for Environment and Energy (KIFEE)	2006	2007
171842	The precautionary principle in nanotechnology: Who should be precautionary? The role of stakeholders in the governance of nanotechnology.	2006	2006
171838	Interdisciplinary Studies of Ethical and Societal Implications of Nanotechnology	2006	2009
169736	Nano science for new advanced metal-hydrogen systems towards applications	2006	2008
169713	Genetic approaches to complex materials	2006	2009
169673	Advanced transmission electron microscopy in catalysis	2006	2011
169737	Nanostructured Polymer and Composite Particles: Mechanical Properties	2006	2011
176392	High-quality nanocarbon from natural gas	2006	2012
176234	Development of ceramic bipolar battery plates using nanomaterials and nanotechnology	2006	2008
176225	Hybrid particles: Design, synthesis and characterisation	2006	2008
176216	Silica nanoparticle binding technology	2006	2008
176115	Utilising nanotechnology for composite materials (Pre-project)	2006	2007
179159	Study of carbon nanotube-modified epoxies as toxin-free, solvent-free primer/coating/paint for marine applications	2006	2006
176485	Nanomaterials for Harvesting Microenergy	2006	2009
176214	Design and Production of Planar SOFCs from Nanoparticles with Emphasis on Support and Sealing	2006	2011
179200	Commercial application of Nano-porous silicon	2006	2006
176231	Biomimicking nanocomposites – thin films and super-strong materials	2006	2008
176390	TLENS (Tunable lens) – A tunable polymer-based auto-focus lens	2006	2008
176212	New innovative barrier solutions for targeted fresh food packaging applications	2006	2009
176425	Carbon fibres and health – design of nanofibres with low toxicity	2006	2008
169659	Heat Transferability in Nanofluids	2006	2008
179253	Effect of ultrasound dosimetry on drug release from liposomes-implications for development of novel acoustically sensitive liposomes	2006	2006
178542	Optics of meta- and (nano-) structured materials: How to engineer textures tailored towards given applications?	2006	2009
188854	FORNY 188584/I10 Verification co-funding	2007	2009
184534	OECD Committee for Scientific and Technological Policy (CSTP)	2007	2008
182280	National initiative for a nanomedicine network	2007	2007
182116	Micro Scale Fire Train	2007	2008
182115	Pre-study of nanoparticles for use in coating applications	2007	2007
181656	ESF Research Networking Programmes – Nanoscience and engineering in superconductivity	2007	2011

No.	Project title	From year	To year
179587	Modeling of particle deposition phenomena in heat exchangers	2007	2010
172663	Entry of Nanoparticles into cells: Characterization of Nanoparticles as tools to study endocytic pathways and intracellular transport	2007	2011
178533	A numerical and experimental study of flow and instabilities in concentrated colloidal suspensions	2007	2010
182294	Innovative nanotechnology-based depot plaster for wound healing and medical treatment	2007	2007
178556	Conformation and Physical Properties of Single Wall Carbon Nanotube-Biomolecule Hybrids	2007	2010
179590	Multifunctional Particulate Systems for Nanomedicine	2007	2010
182091	Modeling and Fabrication of Nanowire Lasers	2007	2012
181839	Hetero-junction Si based solar cells	2007	2011
181823	Nano-particles in adhesive conductive materials	2007	2010
181817	Manufacturing and application of metal coated polymer particles as BGA/CSP balls in electronic interconnect	2007	2011
181785	Functionalised nanoparticles for use in PVC materials and processes	2007	2009
181779	Development of novel sonosensitive liposomes for targeted ultrasound mediated drug delivery – a new paradigm within cancer therapy.	2007	2011
181769	Utilisation of monoisotopic 28Si	2007	2008
182093	Towards the mechanism of formation and function of tunneling nanotubes	2007	2012
182092	NSF-European Materials Cooperative Activity. Nanostructured oxide thin films for organic/inorganic solar cell applications	2007	2011
182090	Development of highly efficient nanostructured SOFCs integrating novel Ln(Nb,Ta)O4-based proton conducting oxides	2007	2011
182075	Michrorheology of nanostructured soft condensed matter	2007	2011
182061	Nanostructured biomaterials for improved vascularization in tissue engineering	2007	2010
182058	Uptake and toxicity of quantum dots in cancer cells	2007	2011
182056	Template based synthesis of nanoporous metal-organic frameworks with high surfaces areas	2007	2011
182043	Governance of the precautionary principle and the nano-consumer: A comparison of ethical aspects in nano-products in Norway and the UK	2007	2009
182018	Nanostructuring of novel semiconductors by ion beams	2007	2011
181995	Thermoelectric materials synthesis, electronic structure, functionality	2007	2012
181884	Thin and highly efficient silicon-based solar cells incorporating nanostructures	2007	2013
181882	Conducting Oxides and Nanostructures for Energy Technology	2007	2012
182044	Carbon-supported core-shell electrocatalysts for oxidation of small organic molecules	2007	2011
182037	Magnetodynamics of Nanostructured Metal Oxides	2007	2012
182035	Immunisation strategies against viral pathogens of Atlantic salmon	2007	2011
182033	Fundamental study of the mechanism for deposition of sol particles on a substrate	2007	2011
181886	Nanomaterials for 3rd Generation Solar Cells	2007	2011
178547	Experimental studies and theoretical analyses of nanoparticles	2007	2007
181808	Nanosized cellulose fibrils as stabilizers of emulsions	2007	2011
182077	Novel catalysts and oriented oxide thin films from exfoliated nanosheets of layered materials	2007	2012
182069	Environmental fate and ecotoxicity of manufactured nanoparticles	2007	2012
182026	Exploitation of naturally formed nanostructured surface films on aluminium alloys	2007	2011
181848	Commercial application of Nano-porous silicon	2007	2008
182047	Nanoscale Control of Mineral Deposition within Polysaccharide Gel Networks	2007	2011
182046	NANOTRUST: Ethical conditions for a socially robust use of nanobiotechnology in aquaculture	2007	2011
182000	Pure and ultra-fine grained Titanium for biomedical applications	2007	2011

No.	Project title	From year	To year
183606	Next generation solar grade silicon and solar cells technology	2007	2009
182040	Novel nanomaterials and nanostructured materials for hydrogen storage applications	2007	2012
178177	High-Power Solid-State Lithium Batteries	2007	2011
182065	Nano-ionics for energy technology (NANIONET)- Integrated theoretical and experimental analysis of surfaces and microstructures	2007	2012
189696	FUGE 175637/S10 co-funding with project 172663/S10 Entry of Nanoparticles into cells: Characterization of Nanoparticles as tools to study endocytic pathways and intracellular transport	2008	2010
187266	Parameter optimization in preparation of membranes for osmotic processes	2008	2012
187247	Hymen bonding as a method for joining aluminium	2008	2009
187250	Environment-friendly binders and paint systems based on modified silica nanoparticles	2008	2011
187269	From Molecular Structures to Mechanical Properties: Multiscale Modelling for Ugelstad Particles (MS2MP)	2008	2012
189716	Laccase-Nanoparticle Conjugates for the Elimination of endocrine disrupting chemicals from wastewater in bioreactors.	2008	2011
201050	ESF Temporary Expert Committee in Materials Science and Engineering (MatSEEC)	2009	2013
193987	Nordic Top-level Research Initiative	2009	2011
193984	ESF Research Networking-programme: 07-RNP 100 Exploring the Physics of Small Devices	2009	2013
190707	The UiB Nano Platform	2009	2012
190367	FASTNMR – Solid-state Nuclear Magnetic Resonance spectroscopy for Material Science	2009	2011
190086	National Graduate-level Researcher School for Nanotechnology for Microsystems	2009	2013
189710	Multifunctional paint coatings for all-polymeric solar thermal collectors	2009	2011
193248	Flexible, transparent conductive layer	2009	2011
189721	Novel Nanomagnetic Oxide Composites: Giant Exchange Bias Storage Devices	2009	2013
187760	Nanoskolen.no – An introduction to nanotechnology and functional materials for non-mathematicians/non-natural scientists	2009	2011
201141	Nano-particles in adhesive conductive materials	2009	2011
193331	New materials for bipolar batteries	2009	2012
193329	Isotope separation of silicon for use in the photovoltaic industry	2009	2010
195912	Fabrication of Robust Ceramic Proton Conductors	2009	2012
195193	Novel low-cost nano-silicon solar cells	2009	2011
195431	Carbon Materials for improved stability of anodes for Li-ion batteries	2009	2012
195491	New production process for lithium-based battery cells	2009	2013
195233	Energy Materials by Atomic Layer Deposition (EMALD)	2010	2013
203559	National network initiative in the area of HSE and ELSA aspects of nanomaterials: SafeNano Network (SNN)	2010	2011
203505	High Strength PVC foam for Wind Mill Applications	2010	2013
218536	ESF Research Networking-programmet 09-RNP-061Advanced Concepts in ab-initio Simulations of Materials	2011	2011
212123	French Norwegian Foundation (FNS) travel grants for 2011 networking meetings	2011	2011
212120	Co-funding of European Nanoelectronics Initiative Advisory Council (ENIAC) with project 217996	2011	2016
203323	Novel Mg-based materials for advanced Ni-Metal Hydride batteries	2011	2013
203502	Nanodesign to Improve the Catalytic layer of the polymer Electrolyte fuel cell (NICE)	2011	2013
210762	Commercialisation of results from previous and ongoing NANOMAT projects. Pilot production of graphene derivatives	2011	2012
210765	Rapid market introduction of new membrane technology for clean energy applications: upgrading the ProboStat with ceramic proton conductors	2011	2012
211984	Co-funding of project 203503 with ELSA project 212008	2011	2014
203503	Integrated project: Socially Robust Solar Cells (SoRoSol)	2011	2014

Programme administration

Programme boards

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