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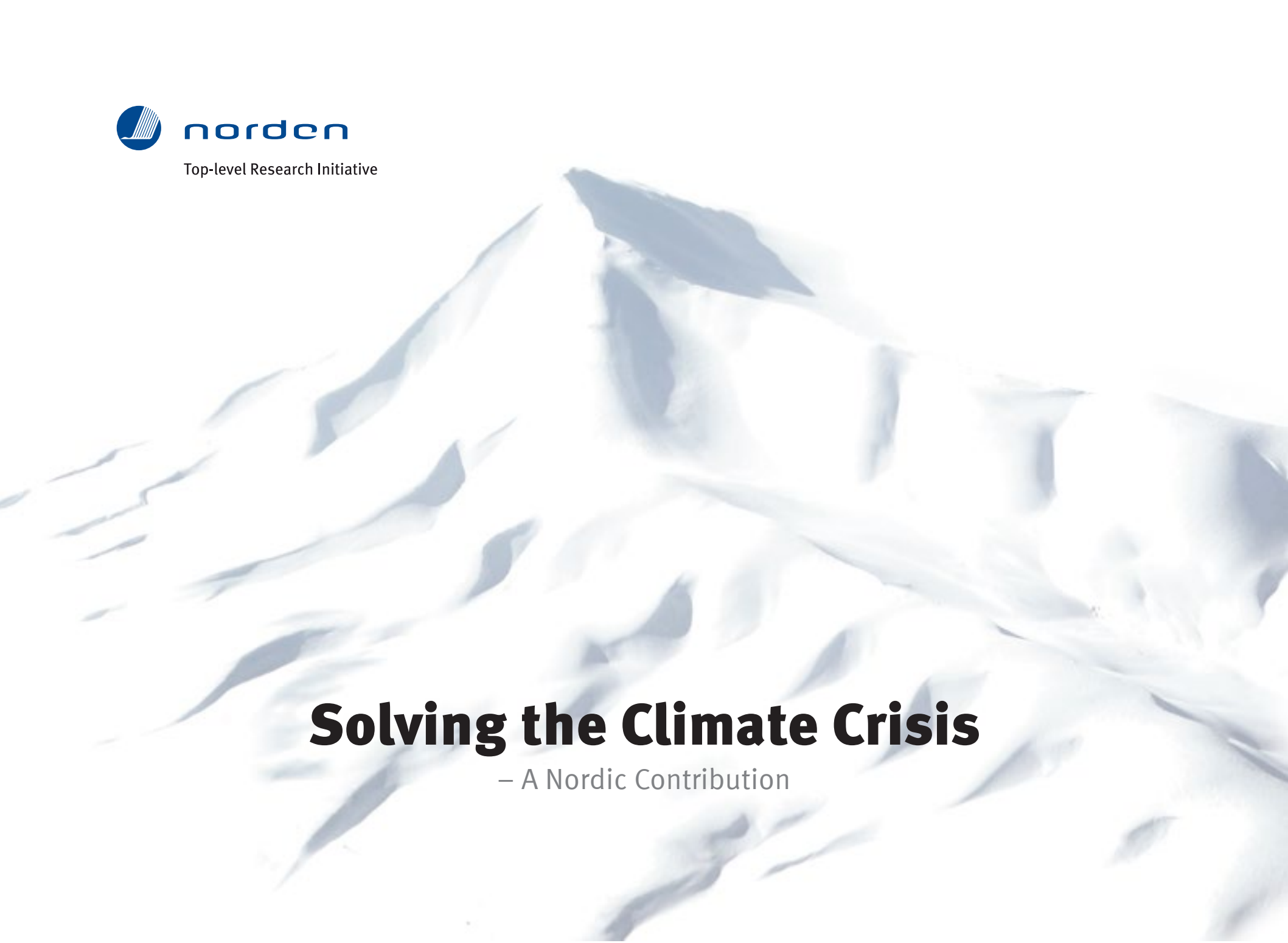
Top-level Research Initiative



Solving the Climate Crisis

– A Nordic Contribution

“I think that the research being conducted here is extremely important in terms of helping us to understand climate change. One of the biggest issues in climate change is what is happening to our cryosphere: ice sheets, glaciers, permafrost, snow. The Nordic countries are really playing a global leadership role here in understanding what is happening to the cryosphere.”

Mark Serreze
Professor at the University of Colorado and Chair of the Scientific Advisory Board of the programme “Interaction between climate change and the cryosphere”

Solving the Climate Crisis

– A Nordic Contribution

At their summer meeting in Finland in 2007, the five Nordic Prime Ministers decided to strengthen efforts related to Nordic research and innovation. They asked the Nordic Council of Ministers to draw up a proposal that would promote Nordic top-level research in close cooperation with trade and industry. The Nordic Prime Ministers met again in April 2008 at the Riksgränsen ski resort in Sweden, where they drew up the Riksgränsen Declaration which laid the foundation for the largest joint Nordic effort to promote research and innovation ever undertaken, focusing on climate, energy and the environment.

The Prime Ministers' pioneering Nordic cooperative effort became the Top-level Research Initiative. This book describes some of the important results from the initiative by the five Nordic Prime Ministers:

Geir H. Haarde, Jens Stoltenberg, Anders Fogh Rasmussen,
Fredrik Reinfeldt, Matti Vanhanen

Photo: Johannes Jansson/norden.org

Jens Stoltenberg in Longyearbyen, the administrative center of Svalbard, Norway. Photo: NordForsk/Terje Heiestad

“I think we should be very satisfied with the results because we have enabled researchers to work more closely together. I think that as politicians, we cannot give you all the technologies, but we can facilitate research, we can provide support, and we can organise activities so that researchers are able to do their job. And that is to expand our understanding, develop technology and thereby increase our capacity to combat global warming.”

– Jens Stoltenberg, Former Prime Minister of Norway and UN Special Envoy for Climate Change.

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NordForsk

Solving the Climate Crisis – A Nordic Contribution

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Preface

The Nordic Top-level Research Initiative (TRI) is the largest Nordic research and innovation venture to date and is within the topics of climate, energy and the environment. It was launched by the five Nordic Prime Ministers in 2007. The TRI was targeted as a Nordic flagship initiative at the Copenhagen Climate Change Conference (COP15) in Copenhagen in 2009 with the aim of contributing to the global knowledge base within climate-related issues and challenges.

In addition to its size and scope, the TRI represented a new type of initiative in that it was divided into six sub-programmes and co-administered by three Nordic organisations: NordForsk, Nordic Energy Research and Nordic Innovation. Expectations were high from the outset, and by the end of the programme period we are seeing that the high-quality research and innovation projects have produced results of international significance.

This book contains a compilation of numerous interviews in which decision-makers and recipients of funding alike express great enthusiasm about the results obtained through the TRI. New dialogue and contacts between researchers across borders and institutions have been established, and new frameworks for interdisciplinary cooperation and innovation development have been built.

We would like to thank all participants in the Top-level Research Initiative at all levels for their contributions to the successful outcomes.

Gunnel Gustafsson
NordForsk

Roger Moe Bjørgan
Nordic Innovation

Hans-Jørgen Koch
Nordic Energy Research

Photo: NordForsk/Terje Heiestad

The largest Nordic research and innovation initiative to date

The Top-level Research Initiative (TRI) is the largest joint Nordic research and innovation initiative to date. The aim of the initiative was to involve the very best agencies and institutions in the Nordic region, and to promote research and innovation of the highest level, in order to make a Nordic contribution towards solving the global climate crisis.

The Nordic ministers of education and research established the Nordic cooperation on top-level research in October 2008. The areas of research involved major global challenges and were addressed at the United Nations Climate Change Conference that was to be held in Copenhagen in 2009. The budget was DKK 400 million over five years, and participating institutions and companies were also expected to contribute financially. By involving knowledge environments and trade and industry and by bringing the foremost Nordic talents together, the Nordic countries sought to develop solutions to the global climate challenges.

High performance

The Top-level Research Initiative (TRI) has produced important scientific results and provided a major contribution to the Nordic research and innovation effort in the areas of climate, energy and the environment. This is the main conclusion in the final evaluation by the independent consultancy firm DAMVAD. The objectives of the programme have been achieved in most areas. The TRI has created a new Nordic and international platform for cooperation on research and innovation. The evaluation shows that the number of scientific publications by the participating researchers has risen in the past four years, and a large percentage of the articles have been published in the most influential journals.

Cooperation between research, trade and industry

The evaluation shows that the interaction between the research community and trade and industry has worked well. Both participating researchers and businesspeople point to the new, beneficial experience they have gained. Commercial results from several projects are expected to be realised in the near future.

Interdisciplinary research

One of the primary objectives of the TRI was to support and stimulate interdisciplinary research, and this has been achieved.

Participating researchers emphasise that they have benefited greatly from dialogue and cooperation with other TRI researchers across the Nordic region who study climate issues from a variety of scientific perspectives. Long-term networks in which researchers can view their own research in a larger,

interdisciplinary context have been established. The TRI has helped to train a new generation of researchers with an interdisciplinary focus, and a large number of younger researchers have got more opportunities and new international contacts.

Productive cooperation

One of the lessons learned from the TRI is that the Nordic countries have the ability to reach consensus and establish a large-scale programme in a relatively short period of time. The TRI was regarded as extremely important, and the joint decision taken at the highest political level facilitated a relatively quick launch of the programme which involved participation from all of the countries.

Organisation

The TRI organisation was established with a Management Board, six Programme Committees (nominated for each of six sub-programmes) and a secretariat for day-to-day activities. The TRI secretariat was jointly administered by the three Nordic organisations – NordForsk, Nordic Energy Research and Nordic Innovation – contributing their combined competencies in the fields of research, innovation, technology and energy. The TRI had a large portfolio of projects, 40 in total. Included in this figure were six Nordic Centres of Excellence (NCoE), a Nordic Competence Centre, and a number of networks and studies.

The first activities and calls were initiated in 2009, and the first projects started in 2010. Some of the grants run until 2017. Throughout the programme's period, many of the participating researchers and business partners have engaged in dialogue across sub-programmes and projects and established new, beneficial cooperation, as well as networks of new contacts within and outside the Nordic region.

The three Nordic institutions

The three Nordic institutions that jointly administered the TRI are all under the auspices of the Nordic Council of Ministers:

- **NordForsk** provides funding for Nordic research cooperation as well as advice and input on Nordic research policy.

- **Nordic Innovation** is a Nordic institution working to promote cross-border trade and innovation.

- **Nordic Energy Research** is the platform for cooperative energy research and policy development in the five Nordic countries.

The TRI vision

The Top-level Research Initiative should:

- Profile the Nordic region as a leader within certain areas of the energy and climate sectors.
- Strengthen national research and innovation systems.
- Create larger professional communities which extend across borders and pave the way for greater mobility of competencies.
- Ensure the highest quality in research and innovation by combining the strongest Nordic communities.
- Provide a platform for increased international cooperation both within the EU and beyond.
- Enhance Nordic participation in EU programmes.
- Strengthen Nordic competitiveness by using research and innovation to counter economic downturns.

The six sub-programmes

In the Top-level Research Initiative, the work was divided into six sub-programmes. Within the framework of these six themes, the initiative also included advanced climate modelling, social sciences and the humanities, and a focus on the Arctic area:

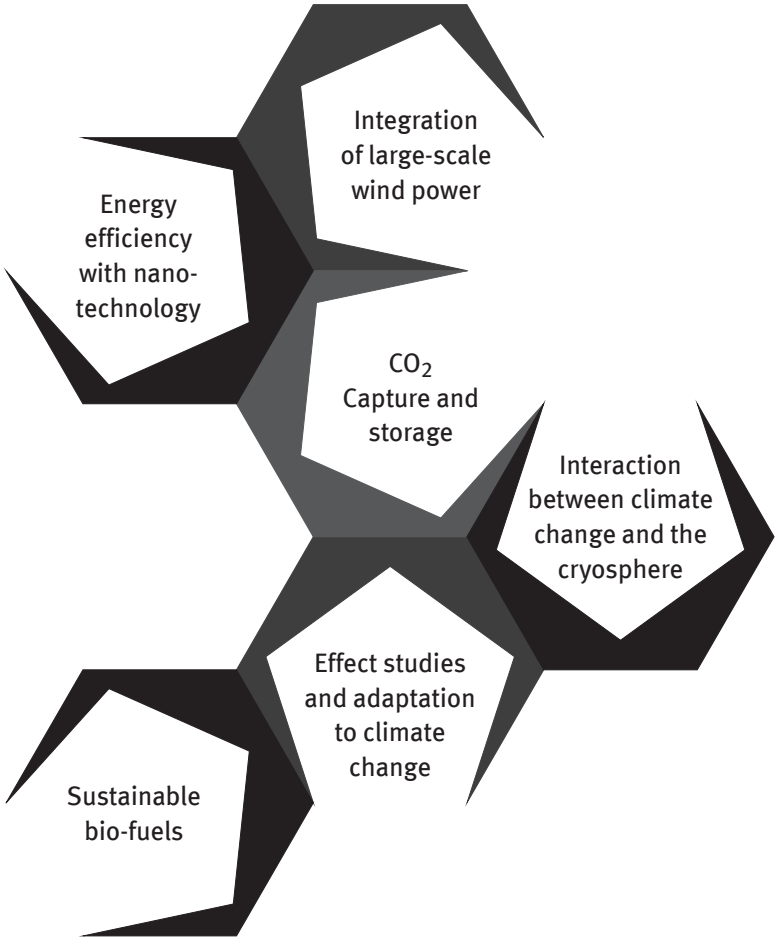
- Interaction between climate change and the cryosphere
- Effect studies and adaptation to climate change
- Energy efficiency with nanotechnology
- Integration of large-scale wind power
- Sustainable bio-fuels
- CO_2 - capture and storage

The Nordic Centres of Excellence

A Nordic Centre of Excellence is an outstanding, creative and efficient multi-site or single-site environment with a joint research agenda, joint management, coordinated researcher training, common communication activities, and collaboration on research infrastructure. Nordic Centres of Excellence are to comprise Nordic researchers at the forefront of their fields, and may include participants from non-Nordic research environments who are needed to fulfil the goals of the centre.

Nordic Centres of Excellence facilitate more efficient use of resources by bringing together people, funding and infrastructure in collaborative entities, thereby enhancing the coordination of research efforts. They promote international researcher mobility, true interdisciplinary research, and the joint use and establishment of research infrastructure. The centres incorporate a targeted international strategy and provide joint access to the best research environments in the Nordic region, thus increasing the region's attractiveness and strengthening Nordic ties to and impact on relevant European research initiatives. Through coordination of researcher education, the centres build competence, establish long-term networks and expand the career opportunities of younger researchers.

The Nordic Centres of Excellence promote both the development and use of research-based knowledge. The joint communication and dissemination activities and coordinated data management conducted at the centres increase the likelihood that the research results will be used both in the scientific communities and by society as a whole. Collaboration with public service providers and industry is encouraged within the framework of a Nordic Centre of Excellence.



Interaction between climate change and the cryosphere

The overarching objectives of the sub-programme were to:
- Reinforce Earth System research cooperation in the Nordic region and beyond
- Improve our understanding of cryospheric stability and dynamics
- Specify cryosphere parameters in Earth System models
- Fund research on scientific issues of great interest to society, science, industry and/or national infrastructure.

The sub-programme consisted of three NCoEs:
NCoE SVALI: Stability and Variations of Arctic Land Ice
NCoE CRAICC: Cryosphere-Atmosphere Interactions in a Changing Arctic Climate
NCoE DEFROST: Impact of a changing cryosphere – Depicting ecosystem-climate feedbacks from permafrost, snow and ice


Interaction
between climate
change and the
cryosphere

NCoE SVALI
Stability and Variations of Arctic Land Ice

Research aircraft, measuring the volume and thickness of ice in glaciers in Svalbard. Photo: NordForsk/Terje Heiestad

Interaction between climate change and the cryosphere

The Arctic is the first victim of climate change

"The first victim of the ongoing changes to the climate looks like it may be the Arctic, as the changes are taking place more rapidly there than elsewhere. We are working to determine how quickly Arctic glaciers are melting due to rising temperatures," says Professor Jon Ove Hagen.

As a result of changes in the global climate system, the glacier fronts of the Greenland Ice Sheet and other areas in the Arctic have receded, and there is more calving from glaciers that terminate in the sea. This increase in melting and calving is causing sea levels to rise, and the influx of cold freshwater to the ocean is affecting ocean circulation.

"These changes are happening more rapidly than predicted. We want to be able to foresee future sea level rise, for instance, and to do this we must develop a better understanding of glaciological processes and include them in global models," states Professor Jon Ove Hagen. He is a glaciologist and Professor at the Department of Geosciences at the University of Oslo. He has also headed the NCoE SVALI since its launch in 2011.

How fast are the glaciers melting?

"The main aim of the SVALI project is to develop more precise estimates of how fast the glaciers in the Arctic are melting. Developments concerning Arctic sea ice are of interest as well, naturally, but other research groups are studying those," explains Dr Hagen.

"The second aim is to try to gain a better understanding of these processes. For instance, if the ice melts faster, it will have an effect on the hydrology and the dynamics of the ice. Faster melting will probably also cause the ice that hasn't melted to slide more quickly into the oceans due to reduced friction between the glacier and the underlying rock."

"Our third aim is to model and predict how fast we can expect the ice to melt in the future based on different climate change scenarios. The input into the models is, of course, the measurements compiled in the two first parts of our investigations, adds Dr Hagen.

Professor Jon Ove Hagen, Head of NCoE SVALI.
Photo: NordForsk/Terje Heiestad

Project title: NCoE SVALI
The Stability and Variations of Arctic Land Ice

Project period: 2011–2016

Fellowships: 10 PhDs and 7 Post-docs. In addition, 14 affiliated PhD students funded by other sources, with support from NCoE SVALI for courses and conferences.

Project partners: 17 partners from 5 Nordic countries

Websites:
NCoE Svali: http://ncoe-svali.org/index.shtml
The Ice School, Denmark: http://isskolen.dk/wp/

Professor René Forsberg of DTU Space, a SVALI work package leader, conducting measurements of vertical land movement by the Icefjord. Photo: NordForsk/Anne Riiser

A large centre

NCoE SVALI is a rather large centre with 17 partners from all the Nordic countries. The centre also comprises an educational programme, with much of the funding going towards the salaries of PhD students and post-doctoral fellows. The centre has a joint Nordic PhD programme under which students can take courses in various countries.

"In addition, the University of Oslo has received large allocations from the European Space Agency (ESA) to study glaciers on Svalbard using ground-based measurements. Danish researchers have received a corresponding allocation from the ESA and have charted glaciers on Greenland using aerial- and ground-based measurements. The two separate projects have been integrated through NCoE SVALI, which has led to more effective use of the combined research funds. Similar examples can be found among many of the NCoE SVALI partners".

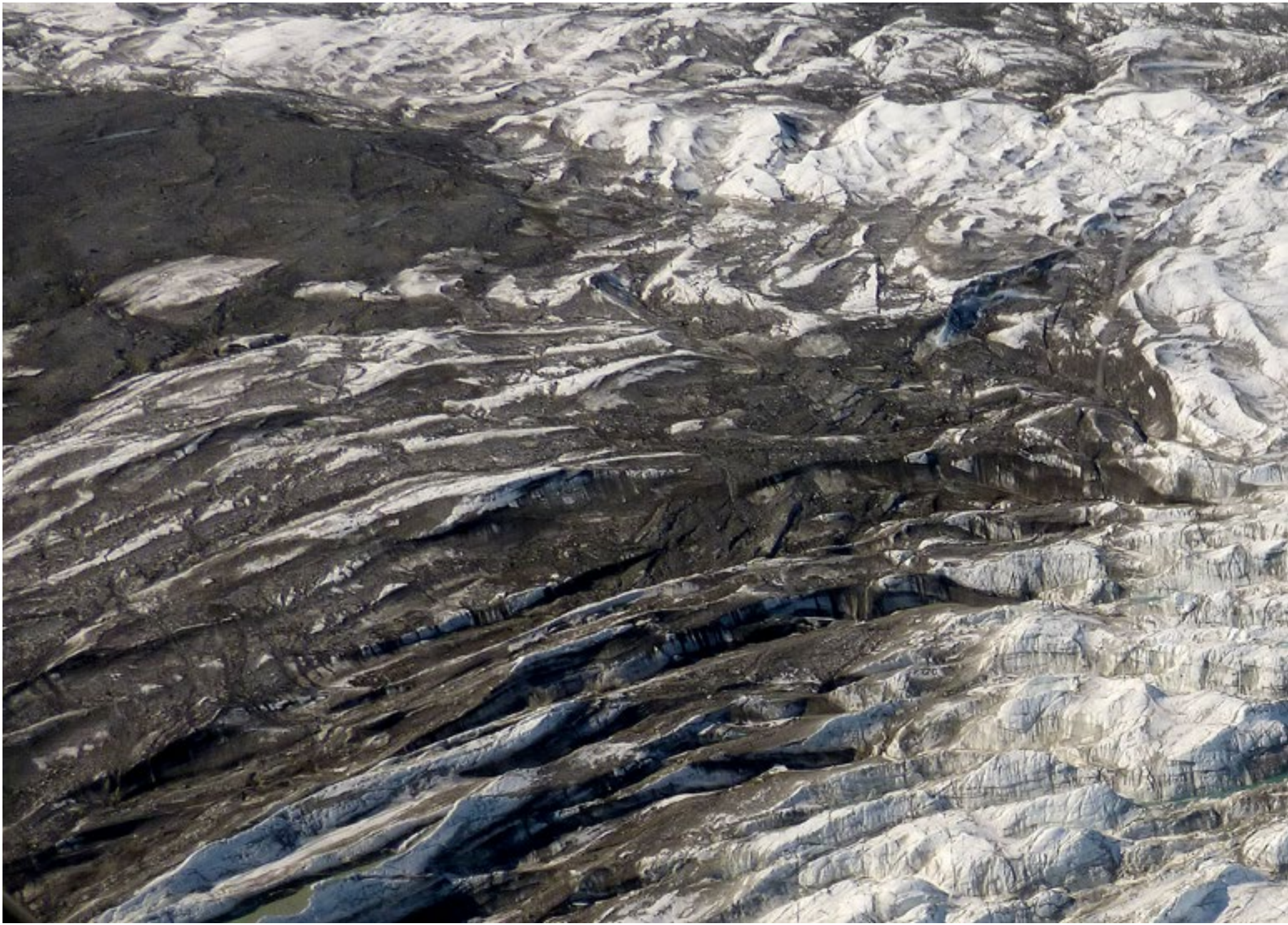
"The centre has worked very well, and has strengthened the network between Nordic research groups. Thus, Nordic climate research has received a boost that will last after activity under the NCoE SVALI has come to a close. Individually, our Nordic research environments are relatively small, but together we have a good deal of clout internationally," Dr Hagen adds.

Sine Munk Hvidegaard, a scientist at the Technical University of Denmark, in a research aircraft, measuring the volume and thickness of ice in glaciers in Svalbard. Photo: NordForsk/Terje Heiestad

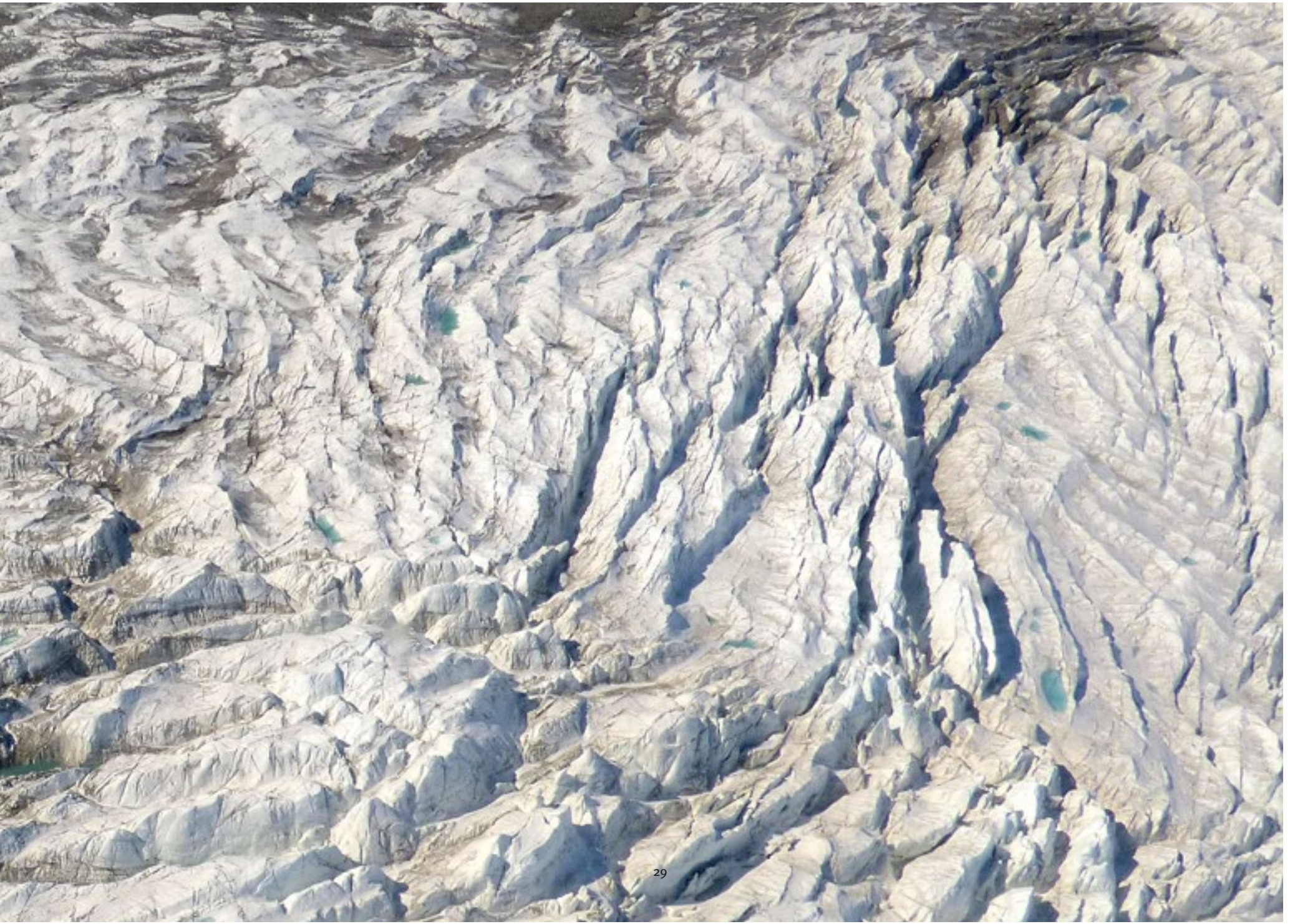
Increased calving could be transitory

Most of the research results generated under the NCoE SVALI will be finalised closer to conclusion of the project in 2016, but the researchers have already discovered certain previously unknown correlations.

"As mentioned, we have observed substantial changes in the Arctic glaciers. This is to a large degree due to increased melting of surface ice, but there has been an increase in calving on Greenland in particular. This indicates a shift in glacier dynamics. We wanted to investigate whether the combination of increased melting and increased calving is a permanent impact, and one of our conclusions is that calving will not be very significant in the future. If we look 50 years ahead, the most important factor behind the loss of ice mass in the Arctic will be surface melt," Jon Ove Hagen explains.



Glacier structure, Greenland. Photo: NordForsk/Jostein K. Sundet



The Ilulissat Icefjord, Greenland. Photo: NordForsk/Jostein K. Sundet

From Greenland. Photos: NordForsk/Jostein K. Sundet

From Ilulissat, Greenland. Photos: Nordforsk/Terje Heiestad

Ilulissat, Greenland. Photo: NordForsk/Terje Heiestad

Ilulissat, Greenland. Photo: NordForsk/Terje Heiestad

Ice School for young students

A group of NCoE SVALI researchers have developed the Ice School, a web-based programme where students between 12 and 15 years of age can study glaciers.

The Ice School started as a Danish project because young Danes – for obvious reasons – are less familiar with glaciers than their peers further north. “Our hope is that this will generate curiosity and, subsequently, a greater interest in science in general,” says Professor Jon Ove Hagen.

“The Ice School is now available in all five Nordic languages, all accessible from the Danish website. We have also established the Ice School in English in order to extend our reach beyond the Nordic countries,” explains Signe Hillerup Larsen. She is a PhD student at NCoE SVALI and has been heavily involved in creating the school.

You can join the researchers

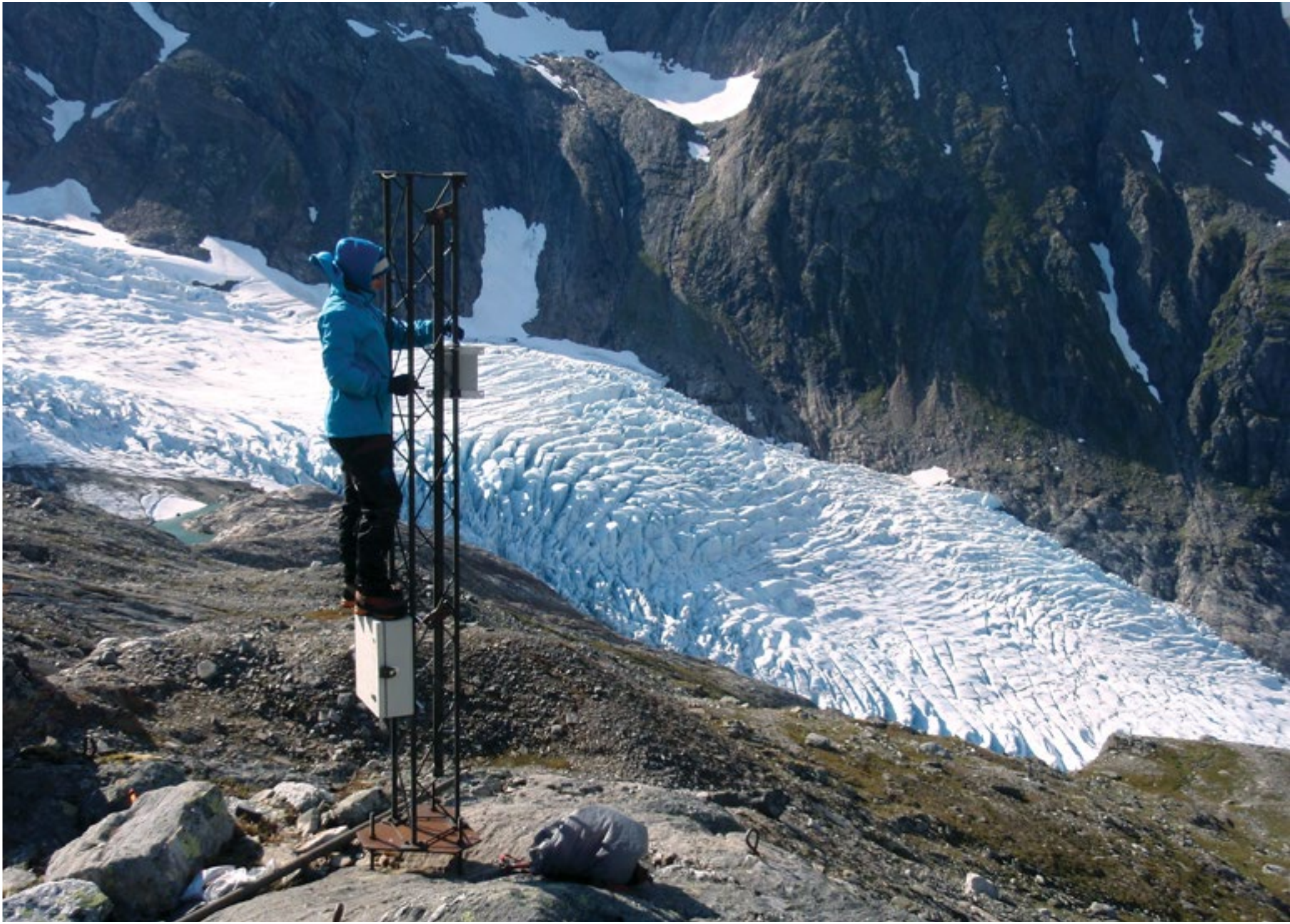
Ms Hillerup Larsen hopes that the Ice School will give research findings a more visible profile and encourage interest. As a scientist, she is modelling the Upernavik glacier complex in northwest Greenland, which consists of four outlet glaciers from the big Greenland Ice Sheet. The glaciers are terminating into Upernavik Isfjord at speeds of about 3–6 kilometers per year. The overall goal of her PhD project is to compile observations from the area and investigate how they can be used to improve our understanding of glacier dynamics, calving and freshwater flux into the fjord.

In the Ice School, you may, for instance, let Pierre-Marie Lefeuvre, nicknamed PiM, guide you through one of the most special research laboratories in the world. PiM’s laboratory is located underneath the outlet glacier Engabreen in Northern Norway. Or you can follow Signe around on top of the Greenland Ice Sheet in the middle of the night. You don’t have to be a teenager to appreciate this kind of research communication!

“The main challenge in teaching schoolchildren is that they have to be entertained and kept active, so the Ice School obviously has to be interactive. Participants have to click their way through the content themselves and have to stop to think about it on their own. It is a real challenge,” explains Signe Hillerup Larsen.

The Ice School, Denmark: http://isskolen.dk/wp/

Signe Hillerup Larsen, here working with Professor Jon Ove Hagen, is a PhD student and one of the enthusiasts behind the Ice School. Photo: NordForsk/Terje Heiestad



Alexandra Messerli at work with the timelapse camera on top of Møsbrømtuva, overlooking Engabreen. Photo: Pierre-Marie Lefeuvre

Monitoring the speed of glaciers

Engabreen is one of the few glaciers in the world that can be examined from underneath via man-made tunnels. In addition, the surface has been studied using time-lapse photography to test out new software that monitors the speed of the glacier. Both approaches provide data on how meltwater affects the glacier's movement.

Engabreen is an outlet glacier of Norway's second largest ice cap, Svartisen, and has been a popular tourist destination for decades. Towards the end of the 1800s, Kaiser Wilhelm II sailed a yacht, the *Hohenzollern*, to Northern Norway in order to view what is one of the world's most low-lying, accessible valley glaciers. Today, ships from the Norwegian *Hurtigruten* coastal steamer line sail through the Holandsfjord giving passengers on deck the opportunity to snap photographs of the wild and beautiful glacier tongue that winds down the mountainside all the way to the waters of Engabrevatnet. The area is also frequented by hikers on their way to Saltfjellet-Svartisen National Park or to the tourist cabin with the descriptive name of Tåkeheimen (Home in the fog).

Alexandra Messerli, a PhD student from the Centre for Ice and Climate at the University of Copenhagen, and the Norwegian Water Resources and Energy Directorate (NVE) has been pursuing a vastly different activity at Engabreen over the past three years. She is a glaciologist studying how varying amounts of meltwater during spring and summer affect the movement of the glacier. Originally from Switzerland, Ms Messerli took her master's degree in glaciology at the University of Cambridge before moving to Copenhagen in 2011.

"We have been very interested in examining how the speed of the glacier's movement varies with the presence of meltwater, which means we need to monitor the rate of motion. However, the glacier is so permeated with crevasses that it was difficult to find a place to put the GPS devices. Then we came up with the idea of placing a time-lapse camera on top of Møsbrømtuva peak instead. The camera has snapped photos of the glacier at a three-hour interval every day from April to September. We have analysed the photos and calculated how fast the ice is moving," Ms Messerli explains.

Møsbrømtuva also deserves special mention due to its peculiar name. *Møsbrøm* is a local delicacy in the form of a spread made of Norwegian goat cheese, water and flour. As reflected in the name, the mountain is a good place to stop for a short snack of *lefse* (a thin Norwegian pastry) and møsbrøm, in addition to being well-situated for monitoring glacier movement.

Studying the glacier from underneath

Alexandra Messerli has been working along with others, including PhD student Pierre-Marie Lefeuvre from the University of Oslo and the NVE. His focus has been on studying the base of Engabreen via the tunnels which make up the Svartisen Subglacial Laboratory. This is one of the world's few laboratories where you can investigate a glacier from underneath.

"Surface measurements of glacier movements and hydrology have been carried out in many places, but here we are also able to gauge pressure and to carry out a number of other observations beneath the glacier. Engabreen is ideally suited to our overall objectives, which are to understand the processes and mechanisms that affect the interactions between the movement of the ice and meltwater. We hope that findings from Engabreen can also be used in developing a better understanding of how other ice sheets, including larger ones, in Greenland and Antarctica, for example, react to variations in the amount of meltwater present," Ms Messerli says.

A toolbox for feature tracking

The most important product of Alexandra Messerli's doctoral research project has been a feature tracking toolbox, ImGRAFT, developed in cooperation with her supervisor, Dr Aslak Grinsted at the University of Copenhagen. The toolbox can be used to analyse time-lapse photos taken by the camera on Møsbrømtuva to generate speed estimates.

"Other researchers have developed similar tools before, but they could only be used to analyse data from satellites and aerial monitoring. This is one of the most complete tools which can also analyse photos and data from land-based cameras," Ms Messerli states.

ImGRAFT is available free of charge and can be downloaded from a dedicated website. It can in principle be used to measure other types of movements involving large masses, such as landslides. According to Alexandra Messerli, it is possible that the tool may be used to analyse older analogue photos of Engabreen taken from the top of Møsbrømtuva in the years 1991–1993.

"The advantage of taking photographs is that it will be possible to map the entire surface of the glacier. With GPS, we have only been able to show the movement at one or more given points," she adds.

Speeding fines unlikely

The speed of most glaciers varies throughout the year, Engabreen included. It is typical for the glacier to move more quickly in the spring when snow on the glacier and in the mountains begins to melt. Water flows down through the glacier and acts like a lubricant between the glacier bed and bedrock.

Engabreen has been monitored during the summer when it reaches its highest speed, but it is unlikely to exceed any speed limits. The middle of the glacier moves by up to one meter per day, a respectable rate of motion for a valley glacier. "But that speed is nothing compared to some of the big outlet glaciers on Greenland. They are moving at a rate of 30 meters or more a day, Ms Messerli explains.

Research laboratory under 200 meters of ice

One of the access points to Svartisen Subglacial Laboratory allows the use of hot-water drilling to melt out ice tunnels in order to gain access to the glacier bed. Photo: Alexandra Messerli

Alexandra Messerli on top of the Greenland Ice Sheet. Photo: Private

THE SVARTISEN SUBGLACIAL LABORATORY was established in 1992 in connection with the development of a hydropower plant in 1992. Statkraft dug intake tunnels under Engabreen to drain meltwater directly from rivers beneath the glacier into the Storglomvatnet lake, which is the power plant reservoir. Permanent tunnels were made through the rock underneath the glacier and lead to access points that open directly at the ice-bed interface, where the 200-meter thick ice mass scrapes along the bedrock.

At one access point, it is possible to use hot-water drilling to melt out ice tunnels in order to gain access to the glacier bed. It is then possible to take samples of ice that are unaffected by atmospheric processes, take a wider variety of direct measurements than can be done using only boreholes and to leave experiments in place from one year to the next, for easy access to them again when needed. The NVE are responsible for the overall operations and maintenance of the Subglacial Laboratory, led by researcher Dr Miriam Jackson.

NCoE DEFROST

Impact of a changing cryosphere – Depicting ecosystem-climate feedbacks from permafrost, snow and ice

Research station at Svalbard, Torben Christensen. Photos: Nordforsk/Terje Heiestad

Interaction between climate change and the cryosphere

“Frightening that we don’t know what we are doing to the climate”

“The global climate system is somewhat like a complex engine we don’t fully understand. We are flipping a lot of switches in emitting large amounts of greenhouse gases, and we don’t know how these will affect the climate engine,” says Professor Torben R. Christensen.

The global average temperature over the past ten years is the highest recorded in 160 years. According to the *Climate Change 2014 Synthesis Report* presented in November 2014 by the UN Intergovernmental Panel on Climate Change (IPCC), climate change may force the world’s population to deal with extreme weather conditions such as flooding, heat waves and droughts more frequently and with higher intensity. Vulnerable land areas will become submerged as sea levels rise. Arid areas may become even drier. There will be impacts on the natural environment and species alike.

The IPCC has also documented that climate change may have an impact on the livelihoods of many people. In addition, disease may spread more quickly, hitting the poorest countries the hardest.

Professor Torben R. Christensen of Lund University in Sweden is among the researchers who have contributed to the work of the IPCC. He is also Head of NCoE DEFROST, which studies how Earth’s frozen soils and waters interact with climate. The focus is on the cryosphere, which encompasses those portions of the Earth’s surface where water is in solid form, comprising sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground (including permafrost).

“We ascertained long ago that the cryosphere is extremely sensitive to very slight temperature changes. This is frightening given current climate predictions,” Dr Christensen says.

The broadest connections

The unique contribution of NCoE DEFROST to Nordic climate research has been its drive to understand the broadest connections. “We are studying how both permafrost in the tundra and ice in the Arctic Ocean affect – and are affected by – greenhouse gases in the atmosphere. In this project, marine scientists, atmospheric researchers, soil scientists and biologists have been working together towards a common goal. For me, that has been the most exciting aspect of the entire project,” says Dr Christensen.

“The whole idea is to bring together the best Nordic scientists,” says Dr Christensen, enthusiastically describing the interdisciplinary cooperation. This is particularly evident in the link between researchers working with sea ice with researchers on land. Traditionally there has been very little interaction between these groups, and, in many ways, they have spoken “different languages”. According to Dr Christensen, this has changed since the DEFROST centre was launched.

Professor Torben R. Christensen, Head of NCoE DEFROST
Photo: NordForsk/Terje Heiestad

Project title: NCoE DEFROST
Impact of a changing cryosphere - Depicting ecosystem-climate feedbacks from permafrost, snow and ice, was established as a Nordic Centre of Excellence (NCoE)

Project period: 2011 – 2016

Project partners: 10 partners from five 5 Nordic countries

Website: http://www.ncoe-defrost.org/home

"Now that we've begun talking together and cooperating on the same project, we are learning many new things and getting new perspectives in our own fields as well. We are gaining greater insight into how everything is connected," he continues.

Permafrost in the freezer

While permafrost is normally found at high altitudes in mountainous regions and on land in areas near the poles, a sample of it can also be found in a university lab at Lund University, not far from Professor Christensen's office. Soil samples containing moss taken from Finland's Kilpisjärvi region are stored in a controlled environment to simulate what happens in nature when the permafrost melts. A myriad of pipes and wires measure the various gases released. In a closed laboratory environment there are no flukes of nature to take into account.

"Combined with the measurements taken at the project's numerous measuring stations in Greenland, Svalbard and in Northern Scandinavia and Russia, among others, these measurements can contribute to a deeper understanding of the interplay between temperature change and greenhouse gas exchange," the professor explains.

Human-caused emissions are the greatest

The DEFROST researchers are eager to find out more about what happens when climate change leads to higher temperatures in the far North. For example, is it conceivable that an increase in vegetation on the tundra could lead to increased uptake of CO_2, thereby mitigating the greenhouse effect? Or will rising temperatures lead to an increase in the tundra's emissions of methane? Professor Christensen believes the answer to both questions is yes.

NCoE DEFROST

"Most predictions assume that a warmer climate will lead to higher emissions of methane from the tundra into the atmosphere. But there is less certainty in predicting how the CO_2 balance will be affected. Certain models suggest that the uptake of carbon on the tundra will be greater than at present, but these models do not take into consideration that carbon emissions will increase as permafrost thaws. Specifically, there will be more erosion which will carry substantially larger amounts of organic materials out to coastal waters, with carbon subsequently being released into the atmosphere."

"Thus there is a risk that climate change in the Arctic will become self-reinforcing. But what may be even more important to consider is that anthropogenic emissions of CO_2 will always exceed natural emissions by a wide margin. Humans represent the major source of emissions, and this will continue to be the case no matter what nature may come up with. People are responsible for the climate change processes currently underway," Professor Christensen stresses.

Norbert Pirk and Torben Christensen en route to a research station in Svalbard.
Photo: NordForsk/Terje Heiestad

Reduction in sea ice increases emissions from the tundra

The widespread reduction in Arctic sea ice is causing significant changes to the balance of greenhouse gases in the atmosphere. This was shown in a study conducted by researchers from Lund University in Sweden and NCoE DEFROST.

Researchers at NCoE DEFROST have collected a substantial amount of information in the three years since the launch of the Top-level Research Initiative, and they will now start the even more intensive process of systematising the information compiled. While a rising volume of findings may be expected between now and in 2016, the researchers have already published a number of articles, including one in *Nature Climate Change* in 2013 that generated wide-reaching debate. Post-doctoral researcher Frans-Jan Parmentier was lead author and Torben R. Christensen was supervisor.

"We have discovered a link between sea ice in the Arctic Ocean and greenhouse gas emissions from the Siberian tundra. Up until a few years ago these processes were assumed to be completely unrelated, but we subsequently demonstrated that greenhouse gas emissions on the Siberian tundra increase as sea ice recedes – and this increase is a *consequence* of the receding sea ice. We were able to prove this connection because we took an integrated approach involving a team of researchers who studied both sea ice and permafrost," Professor Christensen explains.

The researchers observed that the melting of sea ice leads to a vicious circle. Normally, the white ice reflects sunlight back into space. But when the sea-ice cover shrinks, the amount of sunlight reflected also diminishes and a larger proportion is absorbed by the surface of the ocean. This in turn causes warming and contributes to the rise in air temperatures around the Arctic.

On the one hand, the rising temperatures induce more vigorous growth in vegetation, which allows the uptake of more carbon dioxide and is a positive effect. On the other hand, the same temperature rise means that more carbon dioxide and methane are released from the soil, which has a strong negative impact on the climate.

More monitoring is necessary

Torben R. Christensen has subsequently published an article in the comment section of *Nature*. In the article, ***Reduce Arctic methane uncertainty***, he explains the need to expand the monitoring of the variability of methane emissions into the atmosphere from land and sea (methane fluxes) in order to gain greater insight into the relationship between methane emissions and climate change. Professor Christensen recommends broad-based initiatives such as the Top-level Research Initiative because when it comes to the global climate, everything is connected to everything else.

DEFROST scientists creating experimental conditions for the study of CO_2 fluxes in new sea ice. From right: Egon Frandsen, ARC Aarhus Universitet, Denmark; Minica Pucko, CEOS University of Manitoba, Canada; Søren Rysgaard (CEOS University of Manitoba, Canada; ARC, Aarhus University; Greenland Institute of Natural Resources) Photo: Time-laps camera/Kunuk Lennert

Surprising methane emission peaks from the Svalbard tundra

While anthropogenic emissions of methane and CO_2 are contributing to global climate change, natural processes, too, can generate these greenhouse gases. Norbert Pirk's doctoral studies include measuring methane emissions from the tundra on Svalbard to learn more about how these may affect the global climate.

Norbert Pirk initially studied physics at Freie Universität Berlin, but an Erasmus scholarship-funded stay in Umeå in northern Sweden in 2008 sparked a deep interest in the Arctic. From there, his path took him 1 200 km southwards to Lund University where he began working in climate research.

During his Master's degree studies at the university, Mr Pirk developed a new type of antennae capable of measuring the concentration of CO_2 and methane in the tundra soil. This innovation has subsequently led him to Greenland and Svalbard.

"Climate models are telling us that climate change is happening at a faster rate in the Arctic than elsewhere. We believe the Arctic region is particularly vulnerable to climate change, but we do not have much data to tell us what is really going on there. These factors make it extremely important to step up Arctic research. We need to know more," says Norbert Pirk.

Studying greenhouse gases on the tundra

Norbert Pirk is particularly interested in studying methane and CO_2 fluxes in the Arctic, i.e. the flow of these two gases between the land and the atmosphere. Research in this field picked up in earnest in 2007 when activities under International Polar Year led to some additional funding for the Zackenberg Research Station in Greenland. This allowed the research station to extend its operations a few months more into the autumn.

"The extra funding led to some startling findings by the researchers. In the course of about two weeks after the freezing period started, there was a large methane burst. The amount of methane released from the tundra during those two weeks nearly equalled emissions over the entire summer. Up to then we had believed that methane emissions were highest during the summer," Mr Pirk explains.

Emissions of methane and CO_2 from the tundra result from the breakdown of organic materials by microorganisms. The discovery immediately led the researchers to ask a number of new questions: Does this happen every autumn? Does this happen during spring? Is this something that takes place over the entire tundra, which extends across enormous areas in Greenland, Svalbard, Alaska, Canada and Russia?

Higher emissions in Svalbard too

"We don't have the answers yet, but I was able to confirm an increase in methane emissions from the tundra in Svalbard last autumn when the freezing period settled in. It was not as pronounced as in Greenland, but there was a clear increase," Mr Pirk states.

Norbert Pirk is currently collecting data from flux chambers on the surface of the Svalbard tundra, and from systems that measure total emissions over larger areas simultaneously. NCoE eSTICC (The eScience Tools for Investigating Climate Change at High Northern Latitudes) in Kjeller near Oslo, is working to further refine the equipment he is using. The data collected is being used by NCoE DEFROST to study the phenomenon of melting in Arctic regions. Mr Pirk expects to complete his doctorate in a couple of years.

"It's great to have online access to data from the Svalbard measuring stations from my office in Oslo. But the conditions on Svalbard are so severe, especially in autumn, that the equipment needs to be monitored two to three times a week. The University Centre in Svalbard (UNIS) has a master's student on site helping out with this when I am not on Svalbard myself," says Norbert Pirk.

Norbert Pirk is a doctoral student at Lund University and the University Centre in Svalbard (UNIS). He uses flux chambers and other advanced technical equipment to study the production of methane and CO_2 in the tundra on Svalbard. Photo: NordForsk/Terje Heiestad

NCoE CRAICC

Cryosphere-Atmosphere Interactions in a Changing Arctic Climate

The forest of Hyytiälä, Finland. Photos: Nordforsk/Terje Heiestad


Interaction
between climate
change and the
cryosphere

Boreal forests are slowing down climate change

Studies of the northern boreal forests show that they have begun to slow down the ongoing climate change. "Our forests have given us some extra years to save the climate, but we should work hard on reducing the man-made emissions of CO_2 anyway," says Professor Markku Kulmala.

The boreal forests – the taiga – comprise the world's largest terrestrial biome and cover an enormous area between the tundra and the temperate forests in the northern hemisphere. In the Nordic region, these forests cover most of Sweden and Finland, much of Norway, and some coastal areas of Iceland.

The boreal forests and their typical trees – spruce, pine, birch and larch – are both popular among and important for many different groups, such as hikers, hunters and foresters. "Our research shows that these beloved forests are also important for the global climate," says Markku Kulmala. He is an Academy Professor at the University of Helsinki, the director of the university's Division of Atmospheric Sciences at the Department of Physics, and the project leader of NCoE CRAICC.

Focus on the cryosphere

NCoE CRAICC focuses on the ice- and snow-covered regions – the cryosphere – in the northern hemisphere. The boreal forests are included in the cryosphere because they are covered with snow large parts of the year. One of the main objectives of NCoE CRAICC is to identify and quantify the major processes controlling Arctic warming. The boreal forests are now expanding northwards and upwards because of the warming climate, and this expansion is affecting the climate through several feedback mechanisms which the researchers are studying.

"We have suspected for a long time that the northern boreal forests could act as a buffer against global climate change, and our newest research shows that they are doing it already. This happens through two mechanisms: the forests absorb CO_2 when they are growing, so the whole forested area acts as a CO_2 sink. The other mechanism is that these forests act as a large aerosol source, and these aerosols have a cooling effect in the atmosphere," Professor Kulmala explains.

The forests are helping us

The professor emphasises that the forests are not giving us the final solution to the climate problem.

"But they are helping us by slowing down global warming. This means that we will have more time to reduce the man-made CO_2 emissions than we would have had without the forests. It is very hard to quantify the extra time we have been given, but our best estimate is maybe some 20 to 40 years. The point is of course that we must start reducing our CO_2 emissions as soon as possible anyway," he adds.

Professor Markku Kulmala, Head of NCoE CRAICC
Photo: NordForsk/Terje Heiestad

Project title: NCoE CRAICC
Cryosphere-Atmosphere Interactions in a Changing Arctic Climate

Project period: 2011–2016

Fellowships: 16 PhDs, 17 Post-docs and 2 visiting professors

Project partners:
23 partners from 5 Nordic countries

Website: http://www.atm.helsinki.fi/craicc/

European governments and foundations are spending billions each year in buying and protecting rainforests in Brazil and other countries. Even though the taiga makes up 29 per cent of the world's forest cover, it has not received the same kind of attention. The results from NCoE CRAICC suggest that we should work harder to protect our own forests in addition to the tropical rain forests.

"I don't have a quantitative answer to how much the boreal forests are contributing to the climate, compared to the tropical rain forests. But I can tell you that both types of forest act like a CO_2 sink. I can also tell you that the boreal forests are a more important source of aerosols than the tropical forests are," he says.

Measurements for 20 years

The researchers at NCoE CRAICC have been using data from 21 field stations across the northern hemisphere. Professor Kulmala has a soft spot for the research station SMEAR II at Hyytiälä.

"At Hyytiälä, we have measured a lot of atmospheric variables like temperature, solar radiation, the content of CO_2, methane, aerosols and so on, for more than 20 years. During this period we have seen that the forests have increased the production of volatile organic compounds, which again gives rise to increased levels of aerosols in the atmosphere. These aerosols are important for the formation of clouds because they generate a cooling effect in the atmosphere," he explains.

Does this mean that we now have more clouds over the northern hemisphere than 20 years ago?

"No, but the clouds today have smaller droplets than they used to have. This causes them to reflect more solar radiation back into space," replies Professor Kulmala.

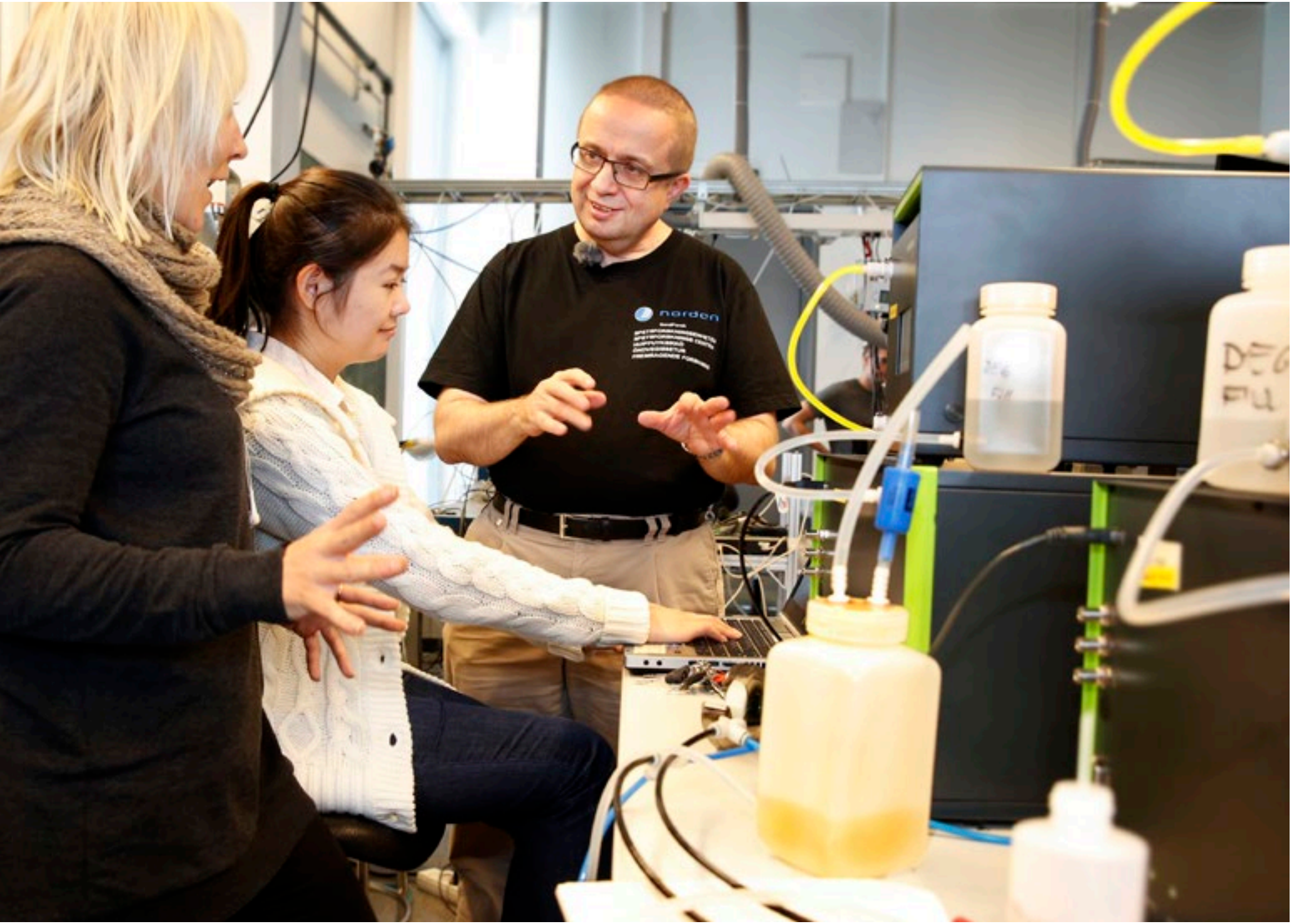
He adds that this result has been very difficult to verify because researchers need data from both ground-based and satellite-based remote sensing in order to measure the size of droplets in clouds and their cooling effect.

Complex situation

The researchers are still working to find out how fast the boreal forests are expanding, and how much they are slowing down global warming. But further north, on the tundra, the opposite effect seems more likely. "The tundra might make matters worse by increasing the emissions of methane from the ground, so the whole situation is very complex. We should also consider the albedo effect, which is a measure of the reflection of sunlight from the snow-covered areas," he says.

Freshly fallen snow has a high albedo, but the albedo from windswept snow or snow polluted with soot or other light-absorbing aerosols is much lower. The albedo in the Arctic region is also vulnerable to changes in snow cover and vegetation.

"To sum it up, the Northern boreal forests are even more effective than the rain forests when it comes to the production of aerosols. They are also pretty effective as a CO_2 sink. But this is still something that we need to know more about in order to produce knowledge that politicians can use when they make decisions about how to combat global warming," concludes the professor.



CRAICC lab, University of Helsinki. Photo: NordForsk/Terje Heiestad

Michael Boy and Juho Aalto next to the 128 meter high observation tower at SMEAR II station. Photo: NordForsk/Terje Heiestad

Nice scents, and they are affecting the climate

A group of chemicals called volatile organic compounds are the reason why the northern boreal forests smell like pine or spruce, but they also have another side: they are affecting the climate, but we don't know how much.

The SMEAR II research station at Hyytiälä, deep in the boreal forests some 200 kilometres north of Helsinki, is the world's largest station for measuring the interactions between the atmosphere and the biosphere. Therefore, it is only natural that the station is helping to fill the biggest knowledge gap in current climate models: aerosols.

An aerosol is a colloid of fine solid particles or liquid droplets in a gas. Examples of natural aerosols are fog, forest exudates and geyser steam. Haze, dust, particulate air pollutants and smoke are examples of artificial aerosols.

"According to the latest IPCC report, aerosols are the largest uncertainty factor in the global climate models. We are not able to understand the climate in sufficient detail without more knowledge about aerosols," explains Michael H. Boy of the University of Helsinki.

Michael Boy is the coordinator of NCoE CRAICC and a researcher at the university's Department of Physics. He doesn't visit Hyytiälä more than once or twice a year himself, but the university has some 50 other researchers who go there on a regular basis. There is also a permanent staff at the site.

A chain reaction

Boy is also the leader of the Atmosphere Modelling Group at the Division of Atmospheric Sciences at the University of Helsinki, where scientists are trying to understand all the processes involving volatile organic compounds (VOC) in the forest. The research station at Hyytiälä has a lot of equipment for gathering data about the production of VOCs and aerosols in a northern boreal forest. The data is fed into a computer-based model, which is subsequently used to study how the entire boreal forest system interacts with the climate.

VOCs affect the climate through a chain reaction: after being emitted from soil or vegetation, they are oxidised by chemical reactions and partly converted into organic aerosols and particles. The aerosols and particles may scatter, absorb or even reflect sunlight, and they are important elements in the processes that lead to cloud formation.

Peaks in spring and autumn

VOCs are produced both below and above ground. The soil in the northern boreal forests is alive with countless numbers of bacteria and other organisms that emit VOCs as they live, eat and multiply.

"Since we started this research at SMEAR II five years ago, we have found that there are strong peaks of VOC emissions from the ground in spring and autumn. The springtime peak appears when the melting snow saturates the soil with water, which boosts the activity of the microorganisms that live in the soil. In the summertime the forest becomes very dry, and this causes the microorganisms to become less active. And then in the autumn, when a lot of needles and leaves fall to the ground at the same time that the rains come back, the organisms become very active and pick up their emissions again," explains Dr Boy.

Communicating with chemicals

A few metres higher up, the trees and other vegetation also comprise a large source of VOC emissions. "The trees produce these chemicals in the leaves, in the needles, in the stems – everywhere. They are not producing them just for fun, but because the chemicals have specific purposes. They may be used for communication between the trees, to attract insects, and for a lot of other reasons we don't understand," says Dr Boy. Vegetation is already known to be a major source of natural emissions of VOCs, but up to now, global climate models have not taken the soil properly into account. The work being done at Hyytiälä will therefore provide important new input for these models.

"Based on our measurements so far, it appears that the soil is the source for between 10 and 40 per cent of the total VOC emissions from the northern boreal forests," Dr Boy reveals.

Volatile organic compounds

Volatile organic compounds (VOCs) are organic chemicals with a low boiling point, which causes them to evaporate or sublimate from liquid or solid form and enter the surrounding air. VOCs are numerous, varied and ubiquitous. They include both man-made and naturally occurring chemical compounds. Most scents or odours are comprised of VOCs.

Three SMEAR stations

NCoE CRAICC is gathering data from three Stations for Measuring Forest-Ecosystem Atmosphere Relationships (SMEAR) in Finland:

- SMEAR I in the subarctic pine forest of Värriö Strict Nature Reserve near the Russian border in Lapland,
- SMEAR II in the southern boreal pine forest at Hyytiälä,
- SMEAR III on the campus of the University of Helsinki.

We are changing everything

According to the researcher, the present man-made climate change is altering emissions of VOCs from the forest. The extension of tree lines in the Arctic region upwards and northwards will lead to more trees and thus probably to greater VOC emissions. The changing temperatures in the soil obviously have a significant effect, as does the length of the period when the ground is covered with snow.

“We have developed some really great global climate models, and there is no doubt that we humans are now changing the climate. But we must always remember that there are also a lot of things we don’t know enough about. VOC emissions from our forest soils are still a more or less uncharted territory, but we have made a good start in mapping this important part of the global climate system,” concludes the coordinator.

Michael H. Boy and Juho Aalto in their “office” in a cabin at the SMEAR II research station.
Photo: NordForsk/Terje Heiestad

Juho Aalto at ground-level at the SMEAR II field station in Hyytiälä, Finland. Photos: Nordforsk/Terje Heiestad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Michael H. Boy and Juho Aalto study measurements taken from close to ground-level at the SMEAR II field station in Hyytiälä, Finland. All photos: Nordforsk/Terje Heiestad

Wetlands affect the climate, and vice versa

Scientists expect climate change to have a pronounced effect on wetlands all over the world because these are vulnerable to changes in the quantity and quality of the water supply. But this is only half the story – wetlands may also have an effect on the climate.

People once thought that wetlands were nothing but a nuisance, but the fact is that wetlands are important in many contexts, such as biological diversity and the global climate. The specific effect on the climate depends on the timescale used, explains Academy Professor Timo Vesala at the University of Helsinki.

Professor Vesala is a meteorologist and an expert on biosphere feedback to climate, a topic that is crucial to understanding global climate change. Finland is an excellent place for studying the feedback mechanisms between wetlands and the climate. Although, the country is often called "the land of a thousand lakes", its wetlands are even more abundant. About one-third of the Finnish land area was covered by wetlands before the process of draining them began.

Absorbing and emitting gases

Professor Vesala has studied wetlands at the SMEAR II research station at Hyytiälä in Finland, as they are similar to many other wetlands in the Nordic countries. They all started out as shallow lakes after the last glacial period, and became filled with peat and other organic material over the course of the thousands of years that have passed. They are now up to 10 metres deep in some places. Vesala has measured the fluxes of greenhouse gases between the wetland and the atmosphere.

"Our measurements show that these wetlands absorb typically 50 grams of carbon, in the form of CO_2, per square metre per year from the atmosphere. That is of course a good thing for the climate. But they are also emitting ca. 10 grams of carbon in the form of methane at the same time because some of the buried organic matter in the wetlands is decaying," explains the professor.

"But this is only a snapshot. At the moment, when the climate is warming, the warming effect of methane from the wetlands is larger than the cooling effect coming from the carbon uptake. But the wetlands have probably had a cooling or at least a neutral effect on the atmosphere over a longer timescale because they have been accumulating a lot of organic material. The wetlands are a carbon sink because they hold a lot of carbon that would otherwise be in the atmosphere," he says.

Managing the wetlands

Professor Vesala points out that it is possible to manage the wetlands better from a climate point of view, partly because the fluxes of greenhouse gases depend on the water level.

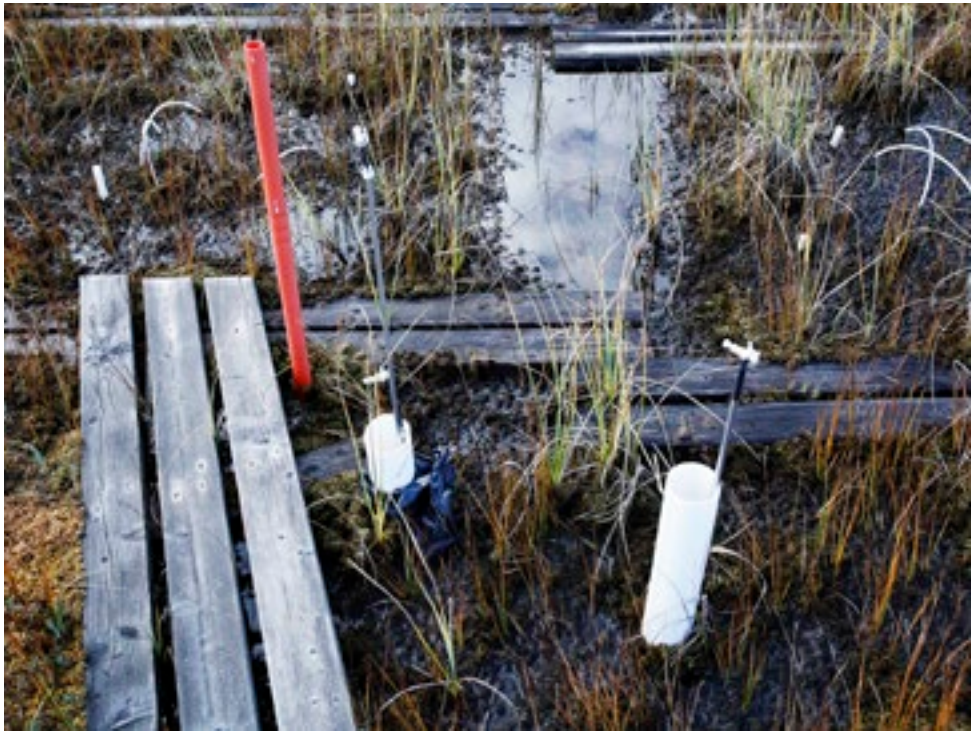
"It is not good for the climate to drain peatlands and turn them into agricultural areas because research has shown that they start to release a lot of CO_2 after draining. These areas continue to release CO_2 even if they are abandoned, but that can be counteracted by growing trees or turning them into wetlands again. Growing trees on drained peatlands is an option because this reduces the methane emissions and creates a new carbon sink in the growing trees. But the wetlands are a large carbon sink in their pristine state, too," he says.

The professor is concerned about the Finnish peat industry. According to the U.S. Geological Survey, Finland and Ireland are the two main users of peat fuel in the world. It has been estimated that the combined climate impact of land-use change, excavation, transportation and burning of peat is comparable to that of coal and oil. This is a hot political issue in Finland because the industry employs thousands of people in mostly rural areas.

Professor Timo Vesala, a meteorologist and an expert on biosphere feedback to climate, monitoring fluxes of greenhouse gases at Hyytiälä. Photo: NordForsk/Terje Heiestad

Partner in three NCoEs

Timo Vesala has been involved in no fewer than three Nordic Centres of Excellence (NCoEs). The first was NCoE NECC (Nordic centre for studies of ecosystem carbon exchange and



The wetlands at the SMEAR II research station at Hyytiälä in Finland are similar to many other wetlands in the Nordic countries. Photo: NordForsk/Terje Heiestad

its interactions with the climate system), which ran from 2003 to 2007 and was coordinated by Professor Anders Lindroth of Lund University in Sweden.

In the TRI-funded NCoE DEFROST, Professors Vesala and Lindroth have led the work package for studying peatland energy balances and energy fluxes. Because energy is coupled to mass fluxes, this type of research helps us to understand the controls of the carbon cycle as well. Professor Vesala has also carried out similar work in collaboration with NCoE CRAICC, which is led by Professor Markku Kulmala of the University of Helsinki.

“The measurements here at Hyytiälä are part of both national and international research programmes, and it is fair to say that we still don’t know enough about the greenhouse gas balance on the boreal and Arctic wetlands. But regardless, the conclusion is that we should take great care in how we treat our wetlands,” concludes Professor Vesala.

Different types of wetland

A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem. The classification of different types of wetlands, such as mires, swamps and marshes, varies greatly among countries. No commonly accepted uniform classification system exists. The best presentation on Finnish, Swedish and Norwegian peatlands and mires may be found in J. Päivänen and Björn Hånell, “Peatland Ecology and Forestry – a Sound Approach”, University of Helsinki Department of Forest Sciences Publications 3, Helsinki 2012.

The wetlands at the SMEAR II research station may look desolate, but they can have an impact on the global climate. Photo: NordForsk/Terje Heiestad

Effect Studies and Adaptation to Climate Change

The sub-programme aimed to improve knowledge about:
- The effects of climate change
- The adaptation capacities of society
- The risks and opportunities that the effects of climate change may bring to the Nordic region

The sub-programme consisted of these three NCoEs, in addition to a number of Nordic networks and other projects:
NCoE Tundra: How to preserve the tundra in a warming climate?
NCoE NORD-STAR: Nordic Strategic Adaptation Research
NCoE NorMER: The Nordic Centre for Research on Marine Ecosystems and Resources under Climate Change


Effect Studies
and adaptation
to climate
change

NCoE NorMER

The Nordic Centre for Research on Marine Ecosystems and Resources under Climate Change

Atlantic cod *(Gadus morhua)* can weigh up to 60 kg and reach lengths of 150 to 200 cm. Its distinguishing feature is a prominent "chin beard". Photo: witoldkr1/Gettyimages


Effect Studies
and adaptation
to climate
change

A threat to cod is a threat to humans

"When human activities pose a threat to the cod, we are in a way threatening ourselves," says Professor Nils Chr. Stenseth.

In earlier times, the story goes, Norway's Borgund fjord could be so packed with fishing boats that you could walk across the fjord without getting your feet wet. This used to happen in the spring, when the fishers were harvesting the cod that came to spawn along the coast.

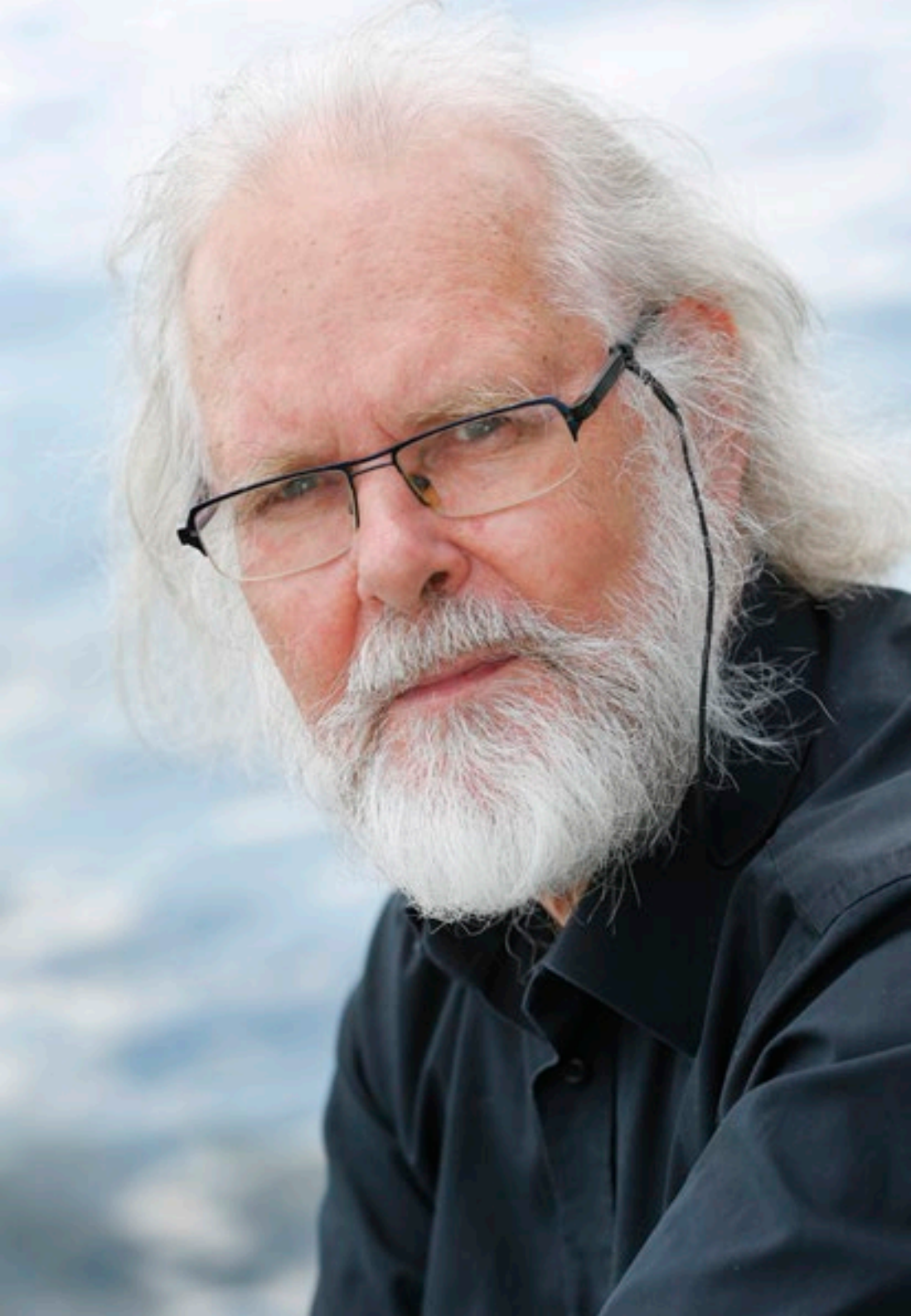
For centuries, Atlantic cod has been a commercially important food source across its entire habitat, which spans from North America, Greenland and Iceland to Great Britain and the Nordic countries. Cod fisheries in the Nordic region have existed at least since the Stone Age, so there was major cause for concern when several cod stocks collapsed in the 1990s. Some stocks are recovering, but Atlantic cod is still labelled as vulnerable on the International Union for Conservation of Nature's Red List of Threatened Species.

"In this research project we are focusing on studying the cod, but on a deeper level it's also about the human race. Many biologists and other scientists, myself included, believe we are now entering a new geological epoch, which we call the Anthropocene (from the Greek *anthropos* = human). This epoch is characterised by extensive changes around the globe brought about by human activity, and cod are one of the victims of this development," theorises Professor Stenseth. He heads both the Nordic Centre for Research on Marine Ecosystems and Resources under Climate Change (NorMER), which is a Nordic Centre of Excellence (NCoE), as well as the Centre for Ecological and Evolutionary Synthesis (CEES), which is a Norwegian Centre of Excellence (SFF) at the University of Oslo.

Fisheries have caused cod to adapt

According to Professor Stenseth, "To be able to sustain human life in the Anthropocene, we need answers to three fundamental questions: How do species – including humans – adapt to the Anthropocene? How should humans adapt to the Anthropocene in order to sustainably co-evolve with the biosphere? And finally, which social transformations are needed to facilitate a sustainable co-evolution? NorMER aims to address all three of these topics. Most of our attention thus far has been devoted to the first topic, but now we are taking action to also address the latter two."

Atlantic cod is an example of a species that has been changed by human activity in a way that ultimately may be to our own detriment. For example, NorMER-affiliated doctoral fellow Anne Maria Eikeset demonstrated in 2009 that the practices of Norwegian fishermen have had an effect on the evolution of cod stocks. The fishermen's nets targeted the largest cod, the



Professor Nils Chr. Stenseth, Head of NCoE NorMER
Photo: NordForsk/Terje Heiestad

Project title: NCoE NorMER
The Nordic Centre for Research on Marine Ecosystems and Resources under Climate Change

Project period: 2011–2016

Fellowships: 17 Ph.D. fellows and 8 post-doctoral researchers

Research partners: 9 from five Nordic countries

Website: www.normer.uio.no

individuals that would fetch the highest price, while smaller cod were able to escape and reproduce. Being small became a survival advantage, and now the cod population is dominated by smaller individuals that become sexually mature earlier – and have less economic value. In the long run, fishermen would probably have earned more by fishing less.

Not just one kind of cod

Researchers at NCoE NorMER have also shown that the cod whose habitat is the southern tip of Greenland are not just one large stock, but actually four genetically distinct stocks that exist in relative isolation from one another and should be managed separately (see related article on page 80). This is valuable knowledge for the resource management authorities seeking to restore Greenland cod to their historic highs.

"The best-known Nordic cod stock, *skrei*, spend years growing large in the Barents Sea, and then they return to Lofoten or other coastal areas to spawn," explains Professor Stenseth. "But there are also stocks of cod that remain in one fjord throughout their life cycle, and these have developed certain genetic differences as they have evolved separately from other stocks. We have carried out projects, some of them before the NorMER centre was launched, to study how various cod stocks respond differently to climatic variations. It turns out that the climate-related increases in water temperature have led to a weakening of the southern coastal cod stocks, while the increased temperatures farther north have had a positive effect."

This can be explained in part by the fact that cod thrive best in cool waters. The optimal summer temperature range for cod growth is 13–15°C, and the fish that live out in the open sea can simply swim northwards to seek cooler waters. The cod stocks that by nature remain in one coastal area, however, grow more slowly due to their now-warmer habitats.

Is climate masking resource management?

Professor Stenseth points out that the NorMER centre produces three kinds of results. "We have trained a number of doctoral research fellows and post-doctoral researchers, we have published a long list of scientific articles, and we have built up a knowledge platform for the marine resource management authorities. The latter is a good example of how biology can have important applications for societal development."

In recent years, cod fishing has once again become viable off the coast of Northern Norway. While the management authorities believe this has been made possible through proper management regimes, Professor Stenseth is not so sure this is the full explanation.

"At the same time as management measures have been adapted, the climate has also been changing in a way that has proved advantageous for the northern cod stocks. No one knows which of these factors is actually more important. Perhaps it's the case that both factors have contributed positively, but it's also possible that climate change is making poor management look good."

Cross-disciplinary win-win situation

As a biologist, Professor Stenseth is particularly proud of the extensive cross-disciplinary cooperation activities under the NorMER centre. "We have, for instance, sent Norwegian ecologists to Finland to learn about economics, and Finnish economists have come to Norway to learn about ecology. One result was an article on how changes in the marine environment may affect the ability to reach international agreements for fisheries management. The researchers warned that it becomes particularly difficult to achieve effective agreements when the natural resource base changes rapidly."

A related cross-disciplinary project produced an article published in the prestigious journal *Nature Climate Change* showing that the Nordic Seas are highly sensitive to environmental change and have been extensively monitored and studied across a broad range of marine disciplines. For these reasons, the Nordic seas may serve as a pilot area for integrated policy development in response to ongoing climate change.

The NorMER centre has served as a platform for developing new Nordic cooperation such as the Nordic Top-level Research Initiative "Green Growth based on Marine Resources: Ecological and Socio-Economic Constraints (*GreenMAR*)"

"When I look back on all we've achieved," continues Professor Stenseth, "there is no doubt that this Nordic cooperation is a win-win situation. Every partner has benefitted scientifically from the cooperation, and it has raised our international profile in both Europe and the US. Activities under NorMER are drawing to a close, but I am sure the CEES centre and other future Norwegian Centres of Excellence in the coming years will incorporate a great deal of Nordic cooperation on their marine activities."

The best is yet to come

"Even though the Top-level Research Initiative is at its end, I am sure that the best from us is yet to come!" says Jason D. Whittington.

Dr Jason D. Whittington, Research Director of NCoE NorMER, is an energetic US-born scientist who started out as an ecological researcher and soon developed a good feel for project management. He has been involved in NorMER since before it was launched, as he led the coordination and writing of the original proposal that later was approved by the TRI.

The proposal outlined NorMER as an international, pan-Nordic research centre administered by the Centre for Ecological and Evolutionary Synthesis (CEES) at the University of Oslo, with nodes and partner institutions in Norway, Sweden, Finland, Iceland, the Faroe Islands, Greenland and Denmark. NCoE NorMER also focused on expanding the Nordic network to include partners outside the Nordic countries. Dr Whittington took on the time-consuming job of recruiting partner institutions, students and post-docs, but his job was made easier by the fact that NorMER had some unique and attractive aspects.

Doubled the money

"One of the important aspects of NorMER was that we asked each of our main partners to match the funding from the TRI. This idea was very well received, and the result was that we built a comprehensive partnership which effectively doubled the scope of what we would have been able to do if we only had used the grant from the TRI," explains Dr Whittington.

Another important aspect was that every PhD and post-doctoral student was required to travel between different research groups. Each student had a main supervisor at his or her home institution, but also had to spend at least three months at an institution abroad as an integral part of his or her project.

Jason D. Whittington and Professor Nils Chr. Stenseth, the chair of CEES and NorMER, soon discovered that both the TRI and NorMER were the focus of a lot of attention. The CEES had a very high international standing and received many applications each time a new project was announced, but the number of applicants seeking a position at NorMER surpassed this entirely. And the positive response did not just come from students. In 2011, Professor Stenseth needed no more than 24 hours to put together a Centre Advisory Panel of international experts for the new Nordic Centre of Excellence. Everyone he contacted accepted the offer immediately. Nordic top-level research had evolved into an international brand.

An interesting afterlife

The scientists at NCoE NorMER have already produced a lot of scientific papers, as can clearly be seen from the long list of "Publications" listed on the website, but the results are still coming in.

"In fact, a lot of the projects are not completely finished. We have had a total of 27 PhD students and post-docs, and most of them are at present working hard on a lot of scientific papers. As these are produced, we are able to synthesise the results from the whole project. It looks like the best results from NorMER will be published after the official end of the TRI," explains Dr Whittington. In other words, the TRI is going to have an interesting afterlife.

Dr Whittington has been actively involved in several of the research projects within the NorMER framework, in addition to serving as its Research Director. In the early months of 2015, he visited the University of California, Davis, while working on a NorMER research project on population dynamics. This necessitated frequent nightly calls to partners and colleagues across the Atlantic.

Wants to continue

"It was really great that the TRI provided funding for NorMER and the other NCoEs. I can tell you that all our partners feel that there has been a huge amount of added value because the money from the TRI really forced us to work internationally. We are now working hard on developing a strategy for continuation because it would be a shame if such a valuable cooperation should come to an end. We haven't just delivered good science, but we have also put a lot of work into figuring out the best way to work as an international research institution. The whole of Nordic science would really lose something good if these centres close down," concludes Dr Whittington.

Jason Whittington, Research Director of NCoE NorMER. Photo: NordForsk/Terje Heiestad

Science led to better cod fisheries management

Overfishing and climate variability have resulted in a collapse of the local and cold-adapted cod population off West Greenland.

The cod off West Greenland has experienced a dramatic decline during the 1970s as a result of overfishing and climate variability over the last century. A recent study found that Greenland is inhabited by at least four different cod populations: West Greenland offshore, West Greenland inshore, East/Iceland offshore and Iceland inshore. However, understanding how the different cod populations have responded to anthropogenic pressures have profound implications for fisheries management strategies.

By using DNA from otoliths, Sara Bonanomi has tracked 80 years of cod dynamics during the historical commercial fishery in West Greenland waters. She is a scientist from NCoE NorMER and the Technical University of Denmark (DTU).

Otoliths telling stories

Bonanomi studied DNA scraped from the surface of historical otoliths, dating from the period between 1932 and 2012 and collected at the Greenland Institute of Natural Resources in Nuuk. The institute has recorded a wealth of data for each otolith, such as where and when the cod in question was caught.

”The Atlantic cod is a cold water species. However, different cod populations may harbour diverging adaptation to the environment and therefore they will respond differently to environmental changes. Of particular note, human impacts and climate change might greatly affect the persistence of a more vulnerable population. Indeed, we discovered that intense fishing pressure and changes in ocean temperature have led to the collapse of the local and cold-adapted West Greenland offshore cod population”, explains Bonanomi.

“Some details: the overfishing during the warm period (1950s-1960s) coincided with rapid decline of the West Greenland offshore cod and with the expansion of cod of Icelandic origin along West Greenland. While overfishing during the cooling period in the 1970s was detrimental resulting in a collapse of West Greenland offshore cod and even hampering the increasing abundance of Icelandic cod.

Advice to fisheries management

The waters off West Greenland are now heating up again because of global warming, so the recovery of the West Greenland offshore cod population has been slow or non-existent.

“When we found out that there are several cod populations in this area, with different responses to overfishing and climate changes, we could use the new knowledge to give advice to fisheries management. Most importantly, our results suggest that tracking the genetic origin of fish harvested may improve spatially differentiated management plans and avoid a biased impact on the most vulnerable populations. This will have important consequences for fisheries management in west Greenland and require that separate quotas are set for the different biological populations”, says Bonanomi.

Otoliths

Otoliths are sometimes referred to as “earstones” or “fish ear bones.” They are hard, calcium carbonate structures located directly behind the brain. Otoliths help with balance, orientation, and sound detection – much like the inner ear of mammals. They are not attached to the skull, but “float” beneath the brain inside the soft, transparent inner ear canals. Fish otoliths can be studied to determine the age of the fish, the environment the fish was living in, which population it belongs to, and so on.

Sara Bonanomi is a marine biologist with fish population genetics as her main focus.
Photo: NordForsk/Terje Heiestad

Otoliths reveal the secret lives of cod

Scientists already knew that they could learn a lot about the lives of fish and their environment by breaking open and analysing otoliths. NorMER researchers have just added a new dimension, showing that the external shapes of otoliths can reveal whether an individual Icelandic cod belongs to a deep migrating stock or a shallow coastal stock.

The Icelandic Marine Research Institute (MRI) has experimented with attaching data storage tags (DSTs) to Icelandic cod in order to record both the temperature and the depths at which the cod are swimming. The DST profiles have enabled the researchers at NCoE NorMER's Reykjavík node to infer the behaviour of the individual cod.

"The MRI found out that one group of Icelandic cod migrates to deeper areas during the feeding season, while another group stays in more shallow waters during the whole year. This is similar to the situation in Norway, where the migrating North East Arctic cod and the Norwegian coastal cod comprise two clearly different groups," explains PhD student Hlynur Bárðarson at the University of Iceland.

Bárðarson wanted to find out if it was possible to distinguish between the two Icelandic cod ecotypes by analysing the shape of the otoliths, as this would make a lot of older otoliths – collected before DST tagging – available for this kind of research. Otoliths in bony fish resemble flight recorders, constantly recording information about the fish's age, growth rate, sexual maturation and spawning periods, not to mention temperature and pollution in the waters in which the fish live.

To glue or not to glue

However, Bárðarson soon encountered a big problem. Data storage tagging is expensive, so there are not too many otoliths taken from tagged cod. A lot of the otoliths from tagged cod had furthermore been sawed in two or broken in half for age determination, destroying their shape. In other words, Bárðarson had trouble getting hold of enough complete otoliths to conduct his study. However, the inventive researcher soon found a solution.

"I found that the otoliths that had been sawed in two could not be used because the sawing removes some of the material. However, those that were simply broken in half were a different story because all the material is still there. It was simply a question of gluing the halves together again. I tested the method by taking shape measurements of otoliths that I later broke and glued together before taking shape measurements again. This showed that there were no significant shape differences. That was a good thing because I could increase the sample size in my project," he explains.

This led him to publish the first scientific paper from the project, with the Hamlet-inspired title “To glue or not to glue? Reassembling broken otoliths for population discrimination”, in the *Journal of Fish Biology* in 2014.

The importance of otoliths

“In Norway, fisheries management distinguishes between the north-eastern migrating cod and the coastal cod. We know that the coastal cod matures faster than the other ecotype, so different fisheries management approaches should be considered also in Iceland. My research shows that otolith shape can be used to distinguish between the ecotypes,” he says.

The differences between the first two-year rings in the otoliths from Norwegian North East Arctic cod and coastal cod are so great that they are visible with the naked eye. The shape differences that the researcher has been investigating, on the other hand, are much smaller and can only be analysed with the help of a computer program.

Bárðarson points out that the otoliths are important to fish, and that without them, the fish would not know whether they were going right or left, up or down, and their hearing could also be impaired. Thanks to Bárðarson’s research, otoliths have been given an even more important scientific status than previously.

PhD student Hlynur Bárðarson at the University of Iceland has given otoliths of Icelandic cod a greater scientific status than previously. Photo: NordForsk/Terje Heiestad

Data storage tags

A data storage tag (DST) is a data logger that records data at predetermined intervals. Data storage tags can have a variety of sensors, such as temperature, depth, light, salinity, pressure, pitch and roll, GPS, magnetic and compass. They can be used internally or externally in fish, marine animals and research animals. They are also used in industries such as the food and beverage industry. At the end of the monitoring period, the loggers are connected to a computer and the data is uploaded for analysis. The tags used in this experiment were manufactured by the Icelandic company Star-Oddi. (Source: Wikipedia)

NCoE NORD-STAR

Nordic Strategic Adaptation Research

Flood in the city of Malmö, 31 August 2014. Photo: Stig-Åke Jönsson/TT/Scanpix


Effect Studies
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Learning climate adaptation from carpenters and village elders

"We need to become much better at learning about climate adaptation from village elders, carpenters and other professionals that have been adapting to changing weather and climatic conditions for centuries," says Professor Michael Goodsite.

When Dr. Michael Goodsite started out as Director of NCoE NORD-STAR in 2011, he and his Nordic team from all five countries and their 10 partners had their sights set on two innovations.

"We were planning to use state-of-the-art modelling and climate visualisation techniques and policy analysis tools to help bridge the gap between adaptation science, practice and policy. We were also going to link climate adaptation to mitigation in order to help both public and private stakeholders to improve strategy development and decision-making," explains Professor Goodsite.

People have been adapting

The climate has always been changing, and people have always been adapting to the changes. NORD-STAR researcher Johannes Klein of Aalto University has pointed out that while municipalities do adapt to climate change, they do not necessarily do so as envisaged in the scientific literature.

This does not come as a surprise to Professor Goodsite, as people and their communities/municipalities throughout the generations have been effecting change at a practical, non-scientific level out of necessity. Inhabitants figured out where to build their houses in order to protect them from the forces of nature. Carpenters and other tradesmen figured out which materials and constructions to use, and so on.

"That's one reason why you still have these wonderful stave churches in Norway: because the builders figured out how to treat wood so that it would last without rotting. In other words, they adapted the materials and the construction to the climate. Though with respect to these wonderful churches, fewer than 30 have been preserved, and increased precipitation can threaten them," cautions the professor, himself a civil engineer.

Solutions can be low tech

Professor Goodsite is worried that too much practical knowledge now has been lost. "We have been thinking too much about using technology to provide the solutions to climate change, and forgotten that the solutions can often be very low tech. Don't build your house where there is a high risk for flooding, rockslides or avalanches! Carpenters and other craftsmen through the centuries have already found a lot of solutions for climate adaptation, we only have to rediscover them," he says.

Professor Michael Goodside, Head of NCoE NORD-STAR
Photo: Aarhus University

Project title: NCoE NORD-STAR
Nordic Strategic Adaptation Research

Project period: 2011–2016

Fellowships: 7 PhDs and 15 Post-docs

Project partners: 10 partners from 5 Nordic countries

Websites:
http://www.nord-star.info
VisAdapt: http://www.visadapt.info/
ViewExposed: http://setebos.svt.ntnu.no/tomasz/gallery/Vul16/
Broken Cities – A Game of Climate Change Mitigation and Adaptation:
http://nord-star.info/index.php/graduate-training/game-pack#sthash.AGe5kflM.dpuf

"Therefore, I am really pleased that NORD-STAR managed to establish a research project where we actually talked to carpenters and tried to learn from them. Building is a regional craft, and you should not expect that carpenters from, for instance, Central European countries have the best knowledge about how to build houses in a climate and area that offers materials with characteristics different from where they were trained," he adds.

A few years ago, the professor attended a climate and environmental meeting at Thule Air Base in Greenland, where scientists were presenting their latest findings about climate change in the Arctic. Goodsite saw immediately that something was missing.

Where were the village elders?

"None of the village elders were present! Had anybody asked them whether they had seen such changes before? Perhaps not. Maybe the village elders already had some ideas about adapting to the new climate? The past might not predict the future, but it might help us understand if the recent changes really are as new as we think they are. We must be better at integrating social science and the humanities in research, both from the start of research projects and in designing our questions."

"We scientists should not be doing this research for our own sake, or for science, but for the people and nature that are affected by the changing climate. And that includes talking to the people, and learning from them," Professor Goodsite insists. "There are researchers whose fields have trained them to do this, and we must involve them and listen and learn from their results."

Moving quickly ahead

According to the professor, there are very few people living in the Arctic, and it may be difficult for them to make their voices heard.

"What we should try to do as scientists is to interpret the signals we are getting from the people, from the climate, and from nature, and use them to try making a difference. What we have been doing so far is not good enough. All the messages from the international climate meetings – I remember at least back to 1990, a year after I started university – have basically been the same, but there is no real international action being taken yet. That is why I believe in getting the 'ordinary' people more involved. We should help them to understand that they have more knowledge about the changing climate, and how we could adapt to it, than many scientists have about their local area and professions," he elaborates.

The professor points out that scientists also need to address certain social aspects of adaptation. “People and communities with resources can adapt to climate changes without too big a problem, but the poorer regions – with the most vulnerable people – are slower to adapt. If I as a professor am feeling uncomfortable about where I live because of a changing climate, I can just move. Poorer people may not have such options. Therefore, one of the ideas behind NORD-STAR was to learn about climate adaptation in the Nordic countries and use the knowledge to help other regions adapt as well.”

A unique combination

NORD-STAR has developed and applied an analytical framework that defines climate adaptation as an actor-based process. The combination of modelling, visualisation and policy analysis is unique and particularly powerful in addressing complex societal adaptation challenges.

NORD-STAR has also fostered an effective dialogue with stakeholders, allowing them to contribute to research, recognise its value and act on its findings. NORD-STAR has established an international training programme for graduate students and practitioners based at the University of Iceland. The University is the perfect place for the NORD-STAR Graduate Training Programme, not just because of the expertise and enthusiasm of its staff, but also because of its location as a natural crossroads between North America and Europe. The programme will be continued beyond 2015.

Michael Goodsite was Deputy Head of Research and Head of Graduate Education at the National Environmental Research Institute, Aarhus University, when NCoE NORD-STAR was established. He is now Professor and Head of the Institute of Technology and Innovation, University of Southern Denmark and amongst other honorary titles, adjunct Professor at the University of Iceland.

Tom Anders Stenbro in a situation he hopes that homeowners can avoid in the future. Photo: Sindre Kinnerød

Find out how climate change will affect your home

Now you can check and find out how climate change will affect your home and the area in which you live. Researchers at NCoE NORD-STAR have collaborated with the insurance industry to develop an internet-based tool that gives homeowners advice on what they should look out for as the climate changes.

The web-based tool VisAdapt was developed in cooperation with four major Nordic insurance companies that, for obvious reasons, have a great interest in climate change and natural disasters. The companies donated funding via NordForsk for research focused on the individual homeowner. The result is an internet tool that allows homeowners to better visualise and assess climate-related risk factors and determine how to adapt to these in the location they are living or planning to build.

The VisAdapt tool: www.visadapt.info

“The tool points to adaptation measures that house owners themselves can implement to reduce their own risk. The cooperation with the insurance companies has been very interesting for us researchers because we have got a much better picture of how different user groups can actually benefit from information that we develop,” explains NORD-STAR researcher Dr Erik Glaas of Linköping University.

“It was very important for us to make an internet-based tool that gives homeowners the possibility to find out how vulnerable they are due to the changing climate, and to receive very clear and easy, manageable advice on how to reduce this vulnerability. But of course municipalities as well as insurance companies themselves can also use this tool to inform themselves of the risks in different areas of the country,” says Tom Anders Stenbro. He was a Corporate Social Responsibility Advisor at the Denmark-based insurance company Tryg Forsikring.

Lolland's paradox: Rising flood threat does not scare inhabitants

A violent storm in November 1872 left a third of Lolland submerged, the Danish government hired 600 workers to build a 63 km long dike. To this day, the dike still shields most of the island's southern coast from the Baltic Sea.
Illustration: Gyldendal Store danske.

Much of the Danish island of Lolland is below sea level, so one would expect its inhabitants to be anxious about changes in the global climate and the threat of rising seas. Yet the Lollanders are actually less worried than the residents of Copenhagen about climate change.

Lolland is Denmark's fourth largest island and is flat as a pancake. Large parts of Lolland are protected by dikes designed to keep the Baltic Sea out, and even larger areas are just above sea level and depend on water pumping systems to remain dry. So does this mean the Lollanders are losing sleep over climate change?

"No, they aren't. While climate researchers are very concerned about the fate of Lolland as the climate shifts, homeowners on the island remain unperturbed," says doctoral research fellow Nina Baron of Aarhus University.

Faith in technology

Nina Baron is one of the researchers at the Nordic Centre of Excellence for Strategic Adaptation Research (NORD-STAR). She has interviewed residents of flats in Copenhagen, owners of single-family homes in the town of Nakskov on Lolland island, and villagers living farther north on Lolland. Ms Baron was surprised to discover that the inhabitants of Lolland did not seem particularly worried about the impacts of the impending climate change.

"This can probably be explained by the fact that homeowners on Lolland are accustomed to parts of the island being flooded from time to time," says Ms Baron. "Flooding is just a natural part of their existence. The Lollanders know their landscape and where the flooding tends to strike, but they have felt little impact because the residential areas are protected with pumps and dikes. They probably understand that if the pumping station up the road fails, they will have a swimming pool for a living room, but technology has served them well so far. They trust the technology to continue protecting them in future floods as well."

Copenhageners talking about climate change

Apprehension is greater in Copenhagen, where even people living on the fourth floor of buildings have begun preparing for a different climate since torrential rainstorms have caused their cellars to flood three times in the last four years.

"These extreme weather events got Copenhageners thinking about climate change and how to defend themselves against it. One immediate response was that people stopped storing things in their cellars in cardboard boxes. They went to IKEA and bought record numbers of plastic storage boxes instead."

"Basically, people don't experience the climate," according to Ms Baron, "they experience the *weather*. The Lollanders don't really notice that climate change is causing more rainfall, because this change has been 'camouflaged' by the dikes and pumping systems in place. But in Copenhagen there is hot debate about how to deal with future extreme precipitation events."

Nina Baron lives on the second floor in a block of flats in Copenhagen. The cellar of her building has been flooded twice in the last four years. The last time caused a power outage, and knocked out her washing machine and doorbell. Photo: NordForsk/Terje Heiestad

The doctoral research fellow offers no guarantees that Lollanders will remain so tranquil about the climate in future.

"I have spoken with municipal and harbour authorities as well, and they express a higher level of concern than among homeowners. In any case, let's hope the Lollanders continue to be spared for large-scale floods," concludes Ms Baron.

NCoE Tundra

How to preserve the tundra in a warming climate

Kevo National Park, Finland Photo: NordForsk/Anne Riiser


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Protecting the tundra, helping the climate

The reindeer in the north of Norway, Sweden and Finland are protecting the tundra from becoming overgrown with mountain birch and shrubs, and this is a good thing for the global climate. But they could use some help from caterpillars, lemmings, voles and even humans.

When NCoE Tundra was launched 2011, the hypothesis was that reindeer play an important role in keeping the Fennoscandian tundra open. This hypothesis has been largely confirmed, but with several new insights.

“One of our results is that reindeer are not able to kill mountain birch trees and shrubs on the tundra. But they are able to prevent birches and shrubs from growing into new areas,” says Professor Jukka Käyhkö at the University of Turku.

Professor Käyhkö is the Head of NCoE Tundra, where scientists are studying the impact of reindeer on the vegetation and the population dynamics of the Arctic-alpine plants that are most likely to be affected by a warmer climate. The researchers are also studying the effects of some other – much smaller – herbivores on the tundra.

A cooling element

According to the professor, there are several good reasons to protect the tundra.

“The tundra is important in terms of biodiversity, which is another way of saying that the tundra is home to a lot of animal and plant species that have no place to go if the tundra turns into forest. The tundra is also considered a cooling element on the face of the earth. The reason is largely that forests are darker and absorb more solar energy than the tundra, especially in springtime,” he says.

This is the reason why climate researchers worry about the tundra: if large swathes of tundra become overgrown with trees and turn into forests – which could easily happen as the climate gets warmer – the result could be even greater global warming.

Cooperating with caterpillars

Much of the tundra in the north of Finland would in fact have some tree cover today if it were not for the reindeer.

“I told you that reindeer can’t kill trees, but the caterpillars of the Autumnal Moth (*Epirrita autumnata*) are perfectly capable of this. In the 1960s we had two large attacks of the autumnal moth in the north of Finland, and the result was that the

Professor Jukka Käyhkö, Head of NCoE Tundra
Photo: NordForsk/Terje Heiestad

Project title: NCoE Tundra
How to preserve the tundra in a warming climate

Project period: 2011–2016

Fellowships: 15 PhDs and 12 Post-docs

Project partners: 9 research partners from
5 Nordic countries

Website: http://www.utu.fi/en/sites/tundra/


ScoutGuard
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mountain birch trees died in very large areas. But the reindeer are the reason why the birch trees haven't grown back in these areas because they eat a lot of birch leaves in the spring. They are also very effective in eating small birch seedlings when they grow from the ground," says Professor Käyhkö.

He hastens to add that even the caterpillars do not really kill the trees, it only looks as if they do. "I asked our ecologists about how old the birch trees are, and the answer is that they are almost eternal. You can cut them down, but they can grow back from the roots if there are no reindeer around," he explains.

Research shows that the reindeer are also cooperating with small rodents, such as lemmings and voles, in keeping the tundra open. While the rodents feast on the ground vegetation, they also do substantial damage by creating a dense network of "highways" across the ground. These road systems are easy to see when the snow melts in spring.

Are reindeer harmful?

To make a long story short, the researchers at NCoE Tundra have shown that it is the combination of the three "players" – reindeer, moths and rodents – that governs the state of the tundra and the expansion of the neighbouring forests.

"We humans have no influence over the numbers of moths or rodents. So the question is: How can we manage reindeer to enable them to be more effective in protecting the tundra?" Professor Käyhkö asks. This is not an easy question to answer.

Reindeer moss inside fenced area. Photo: NordForsk/Anne Riiser

Left: Reindeer mainly eat reindeer moss and other lichens in winter. During the rest of the year, they eat willow and birch leaves, as well as sedges and grasses, too. Reindeer are also feasting with mushrooms in late summer. Photo: ScoutGuard Camera/NCoE TUNDRA

"In the Nordic countries, there is widespread opinion that reindeer are overgrazing the vegetation, and that this is bad both for the ecosystem and for tourism. This leads to the conclusion that their numbers should be limited, but as scientists, we do not see it as black and white. Much of the alleged overgrazing, at least in Finland, is actually due to reindeer being in the wrong place at the wrong time. They are for instance trampling lichens in the mountains in summer when they could have been in the lush forests eating birch leaves and sprouts. Such problems can be resolved by changing the way pastures are rotated," he says.

NCoE Tundra has a plan

The researchers would like to be able to advise the authorities and the herders on the optimal number of reindeer needed to maintain the tundra in a given area. This is not possible today, partly because there is not enough information about what the vegetation in these areas was like decades ago or centuries ago. But the NCoE Tundra researchers have a plan.

"Our aim is to develop a computational model of the whole reindeer management social-ecological system. This will be done in cooperation with the International Institute for Applied Systems Analysis (IIASA) in Austria. Scientific modelling is an interesting approach because it is much faster and cheaper to do experiments with different reindeer management approaches in a model than performing actual experiments on the tundra. There are of course risks in modelling because models are never accurate, but I certainly hope that this will bring us closer to being able to giving advice on optimal reindeer management in specific areas," says Professor Käyhkö.

"This effort has been very valuable indeed because we have got to know so many excellent researchers from other Nordic countries. We already have plans for future research projects. It is certainly a good idea to pool our resources when we are investigating very complex interactions such as between herbivores and plants on the tundra," he concludes.

Three types of tundra

The tundra is a type of biome in which tree growth is hindered by low temperatures, snow cover and short growing seasons.

- The Arctic or lowland tundra occurs in the far Northern Hemisphere, north of the taiga belt.
- The Alpine tundra does not contain trees because the climate and soils at high altitude block tree growth.
- The typical Fennoscandian tundra in the north of Norway, Sweden and Finland is a combination of the two, and is unique in a global context. It is often called an oro-arctic tundra.

Lemming. Photo: University of Turku

Caterpillar of the Autumnal Moth, *Epirrita autumnata.*
Photo: Arto Hakola/shutterstock

Protected from reindeer, but not from caterpillars

You would expect the birch trees on the tundra to grow taller when protected from grazing reindeer, but this is not always the case. Only extreme cold spells can protect the birches from hungry caterpillars.

In his doctoral thesis at Umeå University in 2013, Tim Horstkotte demonstrated how modern forestry techniques make it harder for reindeer to access food during freeze-thaw cycles in winter. The reason is that these techniques tend to create plantation-like monocultures. Reindeer rely on several different kinds of food during the year, and monocultures lack the diversity that the herds prefer.

Dr Horstkotte has now moved his research on the interactions between reindeer and their environment to the University of Turku, where he continues to uncover new and surprising facts. The university operates the Kevo Subarctic Research Station in Utsjoki at the northernmost tip of Finland, where there are several enclosed experimental sites that keep reindeer away from the vegetation.

Something else is eating too

"We know that birch trees are a favourite food for reindeer in the early growing season, when the budding leaves are rich in nutrients. So you might expect to find that the birch trees inside our fences are taller than on the outside, but this is not always the case. It would in fact be quite difficult to see the difference if we suddenly removed the fence," says Dr Horstkotte.

The reason is that something else is eating the birches too: the caterpillar of the Autumnal Moth (*Epirrita autumnata*), a common species in the northern mountain birch forests.

Left: The caterpillar of the autumnal moth.
Photo: Ruben Pinto/Shutterstock

Right: Tim Horstkotte has many instruments in operation at the Kevo Research Station in Utsjoki in the north of Finland, some 100 kilometres from the coast of the Arctic Ocean.
Photo: NordForsk/Anne Riiser

The moth populations are generally stable for several years in a row, before "exploding" approximately every tenth year. This leads to the defoliation of large areas of mountain birch forest, and the moth has even been known to kill the birch forest completely in some areas.

Very low temperatures are the only thing that can offer some protection from the caterpillars. If the temperature drops below ÷36 °C for several days in a row, the eggs of the moths will die.

"The result is that the trees look more or less the same on both sides of the fence. The trees inside the fence are eaten by caterpillars, and the trees on the outside are kept down by both caterpillars and reindeer. The important fact is that the forest has not yet really recovered from the moth attack several years ago, and this is why we cannot find any large differences between the birch trees inside vs. outside the fence. So the most conspicuous difference is a higher amount of lichens inside the fence. Lichens are the most important winter grazing resource for the reindeer, so it makes sense that the lichens will grow more if the reindeer can't eat them," he explains.

The hidden differences

There are probably also several other differences between the inside and the outside of the enclosure, and together with his colleagues, Tim Horstkotte has a number of instruments trained on uncovering them.

"Similar experiments with fences have also been done in several other places in the Nordic countries, but the unique thing with this experiment is that the fences have been standing for 40 years. This makes it possible for us to investigate the long-term effect on the abundance of vegetation classes inside and outside of the enclosures. We are also measuring soil temperatures and moisture levels at a depth of 10 centimetres on both sides, and we have automatic cameras that record the snow depths in the area."

"We haven't analysed all the data from these measurements yet, but the hypothesis is that we are going to find higher soil temperatures inside the fences. The reason is that there is more low ground vegetation inside the enclosure, and this should offer some insulation. Higher temperatures might increase the activity in the soil and accelerate the cycling of nutrients, which again could lead to faster growth of vegetation. But we won't know if the hypothesis is correct until we have completed the experiment," concludes Dr Horstkotte.

Reindeer better than their reputation

The reindeer husbandry practised by the Sámi people in the Norwegian, Swedish and Finnish northern areas is often blamed for overgrazing and ecological catastrophe, and the industry tends to be seen as blocking other forms of development. Talking to those who actually herd the reindeer, however, provides some surprising new insights.

Antti Aikio and Åsa Larsson Blind were very well received when they approached reindeer owners in six rural regions across Finland, Norway and Sweden about workshops and dialogue meetings to discuss various issues related to reindeer husbandry, climate change and societal conditions in general. It was clear the owners found it positive to meet researchers who did not have the usual "outsider's perspective" on reindeer husbandry, but were interested in listening to and learning from their personal experiences.

Mr Aikio and Ms Larsson Blind both come from reindeer-herding families. Mr Aikio is a student at the Faculty of Law at the University of Lapland in Rovaniemi, Finland, while Ms Larsson Blind has a Master's degree in Human Resources Management and Development and is a researcher at the university's Arctic Centre.

The herder's own perspectives

"My starting point for this project is the herders' own perspectives on the management of reindeer stocks and land management. In a Sámi reindeer-herding context, reindeer are not only a resource, but are also closely linked to Sámi culture and society. Therefore it is important to focus on social factors when trying to understand Sámi reindeer management," Åsa Larsson Blind explains.

"Our project is a bit different from other projects under NCoE Tundra, which are being carried out by biologists, meteorologists, climate researchers and other types of natural science researchers. But NCoE Tundra has preserving the Arctic tundra in the face of climate change as its focus, and we believe there is wisdom in speaking with the people who have a long tradition of reindeer husbandry in these areas. Moreover, new research has emerged in recent years that shows that reindeer husbandry can also aid in maintaining the tundra as an ecosystem," Ms Larsson Blind adds.

Important to talk about the weather

Nina Baron, a Danish TRI researcher (see page 94-95), has pointed out that, in principle, it is not changes in the climate that most people in Denmark are experiencing, but rather changes in the weather. The same applies to the reindeer herding areas, but in a different way.

Reindeer husbandry. Photo: University of Turku

“People always talk about the weather when they meet, and many think this is just small talk. But for those working with reindeer it’s an important topic, because weather conditions and winds in essence are at the basis of the entire industry. Changes in weather mean changes in how these herders work. And people who work outside in nature each and every day can really notice changes, both from day to day and in the long term,” Ms Larsson Blind explains.

In the meetings that have been held thus far, the researchers have heard many accounts of how grazing areas have changed, which in turn led to discussions concerning possible causes.

“This has given us insight into changes which may have been taking place over a long time. In reindeer husbandry, know-how is handed down to younger herders from their elders, which entails that the reindeer owners of today have often received knowledge from those who herded reindeer two generations before them,” states Åsa Larsson Blind.
The findings of the project will be presented towards the end of 2015.

Åsa Larsson Blind is a researcher at the University of Lapland’s Arctic Centre in Rovaniemi.
Photo: NordForsk/Terje Heiestad

Energy Efficiency with Nanotechnology

The overall scope of the sub-programme was to improve the efficiency of future sustainable energy systems by applying nanotechnology to the transport sector, energy conversion and energy use.
Significant value added was expected from this Nordic cooperation by:

- Facilitating user-driven development of sustainable energy solutions enabled by nanotechnology approaches for commercialisation.
- Enhancing Nordic cooperation and augmenting society-industry-academia interaction and international involvement


Energy
efficiency
with Nano-
technology

Enesca

The organic energy storage device project

Green algae at sea bottom. Photo: Stephan Kerkhofs/Shutterstock


Energy
efficiency
with Nano-
technology

Turning algae into batteries

Many researchers dream of being part of a discovery that changes the world. For Maria Strømme and her partners, this dream just might come true.

In 2013, researchers at the Ångström Laboratory at Uppsala University and their industrial partners designed a prototype for an environment-friendly battery. “Our project has shown that it is possible to develop an environment-friendly battery that works,” states project leader Maria Strømme. The prototype can be recharged and discharged thousands of times over without its capacity diminishing.

More science than fiction

While this may have been just science fiction a few years ago, it is now more science than fiction.

The idea behind the battery, made of cellulose-based paper derived from algae, bioplastics and saltwater, was born in 2007. In connection with the TRI subprogramme, Enesca, *“Energy efficiency with nanotechnology”*, the research group has been working closely together with Nordic industrial partners. They started off with a concept at the laboratory stage, and have now developed a functional prototype

“It is really great to be part of this interesting research behind developing environment-friendly energy-storage devices. It is both challenging and rewarding!” exclaims Dr Strømme. Initially, this environment-friendly battery will not be able to match the energy density of the lithium ions batteries in use today. “But during this project we have seen that it’s possible to link small, electroactive molecules to the material in this prototype, thereby increasing the energy density,” she explains.

Polluting green algae

The new battery concept, which Dr Strømme calls a supercapacitor, has many advantages over modern batteries, including the fact that it is environment-friendly. Shortly after defending her Ph.D. thesis in 1997, Maria Strømme discovered some very special traits in the cellulose in the green algae, *Cladophora,* which is known for polluting beaches. The surface area of the algae cellulose per gram was an astounding 100 square meters and its crystallinity was very high. Dr Strømme had previous knowledge about the algae’s cellulose from pharmaceutical research into it as a binding agent in pills.

“But then at the Ångström Laboratory we discovered that it was possible to coat each Cladophora cellulose nanofiber with a layer of a conducting polymer (bioplastic) without altering the large surface of the material. This triggered all kinds of ideas. This surface should make it possible to transport a very large number of ions in and out of the polymer very quickly,” the researchers reasoned. Would it be possible to use this to make a completely new type of battery?

Professor Maria Strømme, head of Enesca
Photo: NordForsk/Terje Heiestad

Project title: Enesca
The organic energy storage device project

Project period: 2010–2013

Participating institutions: Uppsala University, VVT Technical Research Centre of Finland LTD, FMC Bio Polymer AS, ETC Battery and FuelCells Sweden AB, FOV Fabrics AB, Sweden

Website: www.energyscandinavia.eu

Two hundred interviews in the first month

Once news spread about the group having a prototype battery in place based on the conducting polymer, some saltwater and cellulose from algae – and that the battery could be charged in 10 seconds – it became impossible to do any work in the Uppsala laboratory. “In the first month after our press release was issued I was interviewed more than 200 times. The first 20 were fun...”

The world needs new batteries

Battery technology is the Achilles heel of alternative energy. Batteries are in use practically everywhere, with lithium batteries currently far ahead of the rest of the field. But producing these batteries requires a lot of energy and access to raw materials which are in short supply. The world is crying out for a more environment-friendly way to store electric energy.

“Today’s lithium ion battery works well, but has a limited area of application. There are also limits to how big they can be because of the risk they will explode. Modern batteries are also not flexible, whereas our new concept battery can be.”

Milk cartons and sportswear

Maria Strømme thinks it is hard to know precisely where the batteries she is in charge of developing will first be implemented, but she believes they will most likely be used in areas where it is not feasible to use batteries today.

“We are not setting out to replace batteries in mobile phones or laptops. Instead, since these new batteries are made of flexible, paper-based materials, we have our sights set on entirely new areas of application.”

Dr Strømme believes that batteries could be integrated into milk cartons to indicate the freshness of their contents in just a few years, if the packaging industry is interested. Similarly, batteries incorporated in sportswear could help to keep track of distances for runners and how many calories they have used.

In need of a commercial partner

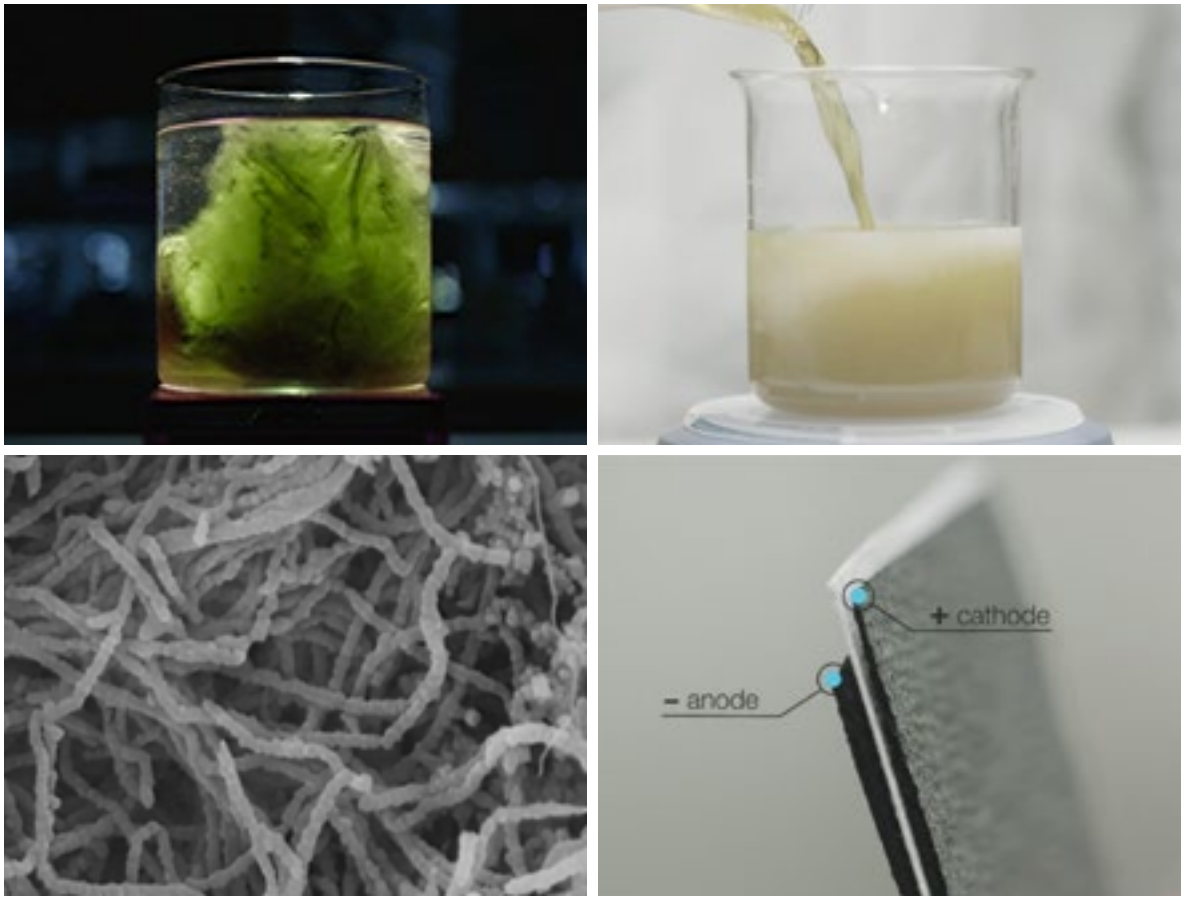
The Professor of Nanotechnology has seen her basic research transferred into applied research on several occasions. But she also knows that things take time. And she openly acknowledges that even though the invention works, a lot has to be done before it can be commercialised.

The researchers in the Enesca project have been actively working to move a product closer to the market. They had nearly completed the development of a TV remote, but the company they were collaborating with was acquired mid-project by a larger actor who was unwilling to invest. “Our problem is that this technology is almost ahead of its time. When looking for industrial partners capable of integrating the battery into their products it is difficult to find any bold enough to lead the way and develop something entirely new.”

“Now we need to find someone willing to make it happen. We are currently working very hard to find an industrial partner willing to think a little outside the box.”

Professor Strømme's research has been rewarded with more than 30 patents and 200 scientific publications. Photo: NordForsk/Terje Heiestad

From left: Martin Sjødin, Maria Strømme and Mushtaq Latifzada, Uppsala University. Photo: NordForsk/Terje Heiestad



From green algae to organic battery:
http://energyscandinavia.eu.preview.binero.se/Archive/Video.aspx

graphene molecular structure

Nanordsun
Semiconductor nanowire-based solar cells

Graphene molecular structure. Illustration: Ekaterina Shilova/Shutterstock


Energy
efficiency
with Nano-
technology

Nordic Research has found its place in the sun

In recent years Nordic researchers have made major breakthroughs with a new type of solar cell technology that could lead to more profitable and efficient solar cells than those in use today.

Nordic solar cell research groups have come together under the Nordic Top-level Research Initiative (TRI), in an effort that may lead to some remarkable results and catapult Nordic solar cell research into a leading position in the future.

Helge Weman, Professor at the Norwegian University of Science and Technology (NTNU), has headed the collaborative effort under the Nanordsun project, “Semiconductor nanowire-based solar cells”.

Dr Weman, originally from Linköping, Sweden, has been working at NTNU in Trondheim, Norway since 2005. When he learned about the call for proposals under the Top-level Research Initiative he contacted a number of people he knew from Lund University in Sweden who were world leaders in this research field. Together with colleagues at Aalto University in Finland and at KTH Royal Institute of Technology in Sweden, they submitted a proposal for TRI funding.

The partners had each been working on their own to find solutions based on new types of solar cells. Now they have pooled their various areas of expertise to work together.

More efficient at capturing sunlight

Normal solar cells are flat. The researchers from the Nanordsun project are studying the use of solar cells comprising vertical nanowires.

These nanowires allow sunlight to be captured and converted into electricity much more efficiently. This in turn means that it takes vastly less material to make these cells compared to normal solar cells. The discovery holds enormous potential for basic research and the commercialisation of research alike. The project initially enlisted two companies, Sol Voltaics and Obducat, which had ideas on how solar cell technology could be scaled up and commercialised. A third company, CrayoNano, was established while the project was underway.

Forced to keep a secret

Before the project was established, Dr Weman and the research group at NTNU had already made a major breakthrough that they had to keep a secret from their consortium partners: They had succeeded in growing semiconductor-nanowires on the wonder material, graphene. Graphene is the thinnest material known, and at the same time one of the strongest. The discovery was heralded as a revolution in the development of solar cells and LED components because graphene can function both as an ultra-thin substrate and as an excellent transparent electrode for solar cells.

Professor Helge Weman, Head of Nanordsun.
Photo: NordForsk/Terje Heiestad

Project title: Nanordsun
Semiconductor nanowire-based solar cells

Project period: 2010-2013.

Participating institutions: Norwegian University of Science and Technology (NTNU),
Lund University, Aalto University, KTH Royal Institute of Technology,
Sol Voltaics AB, Obducat AB.

Website: www.iet.ntnu.no/projects/nanordsun/NaNordSun_The_Consortium

Graphene conducts electricity at a rate 100 times faster than silicon, which is currently the most important component of both electronics and solar cells. And solar cells made with a graphene substrate require far less material than those made using silicon.

“Our colleagues in Finland had begun working with graphene before our consortium was formed, but we couldn’t tell them about our breakthrough until 2012, after we had submitted our patent applications. It was a slightly awkward situation; I’m not used to keeping secrets from my research colleagues,” Dr Weman confides. The company CrayoNano was launched in 2012 and was integrated into the project.

Parallel processes

The project has focused on research and commercialisation as two parallel processes. “It’s an absolute must,” Helge Weman says. “Our commercial partners have an entirely different orientation than we do. They are focused on whether our work can be converted into a product, and if it can turn a profit. This forces us to step outside of our normal mindset as researchers.”

A Nordic catalyst for something greater

Helge Weman explains that the Nordic project, concluded in 2013, has served as a catalyst for further collaboration, and new projects have followed. Among other things, NTNU, CrayoNano and Aalto University are cooperating on research projects on graphene funded by the Research Council of Norway.

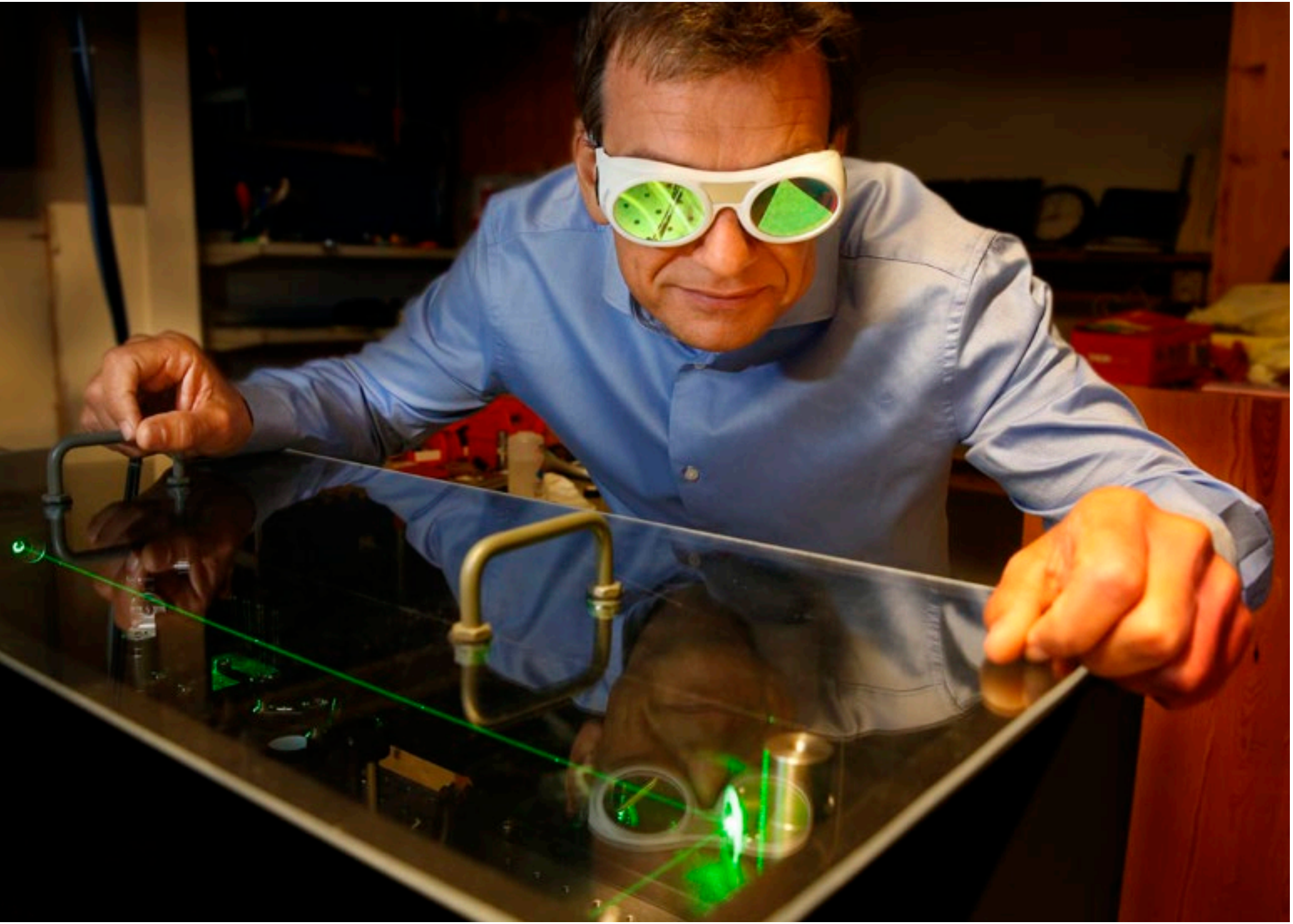
These partners are now discussing submitting a proposal for EU funding together with new European partners. Dr Weman believes that Nordic instruments are an untapped resource. “Too little money is being directed towards Nordic research activity. I think it would be better to take more funding from each of the national research councils and put it in a common Nordic pot. This would make it easier for us to have an impact in European research collaboration,” he says.

A commercial product in five years

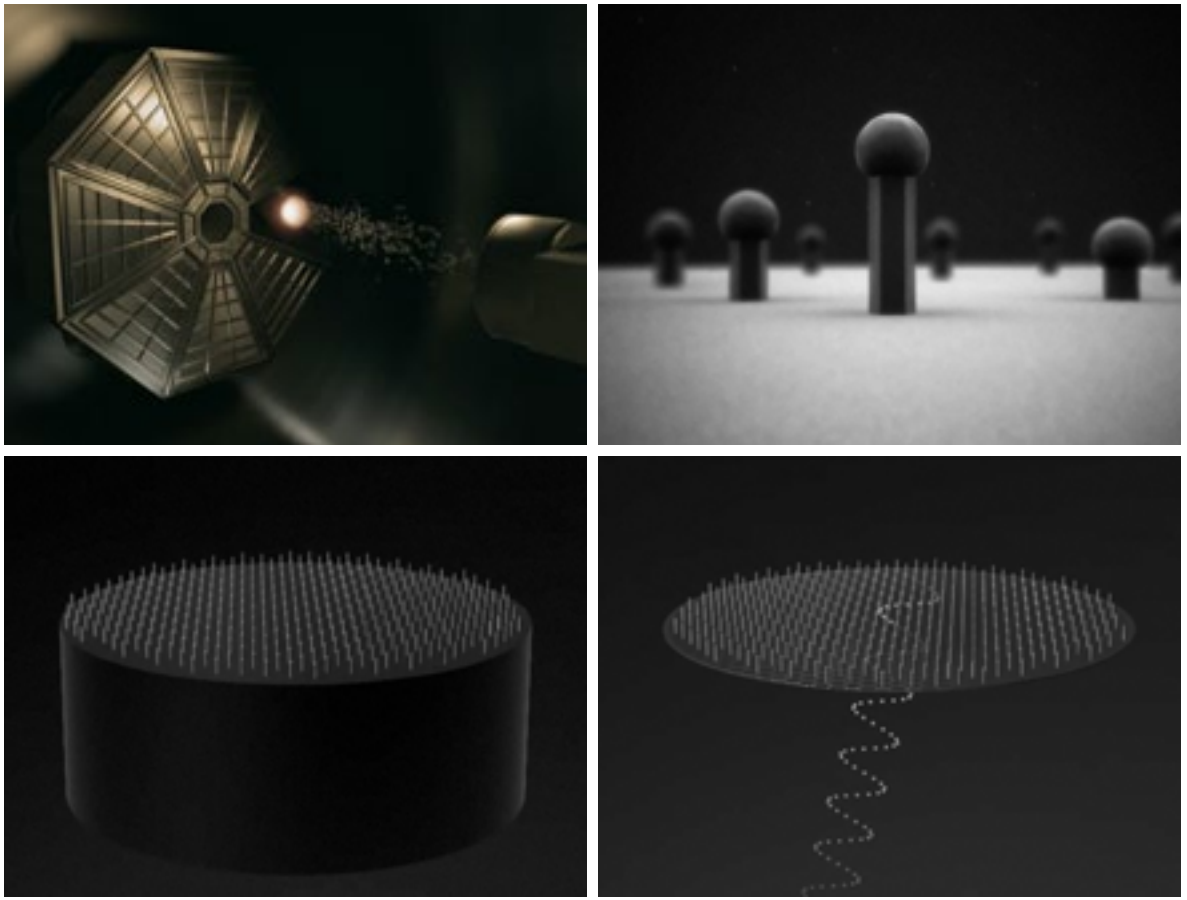
CrayoNano is currently making prototypes of solar cells and is in talks with companies interested in collaboration. This would not have been possible without the Nordic Top-level Research Initiative, according to Dr Weman.

“The company would not have been able to find top-notch partners nor would it have worked as effectively without the Nordic network.” Helge Weman foresees that their products will be on the market in a relatively short time. The first products expected to emerge are chargers for portable products, solar cells for satellites, electric cars with solar cell roofs or parking spaces incorporating solar cells to charge electric cars.

“At present, solar cell technology is being exploited far too little. Only one per cent of the world’s electrical energy comes from the sun, but this can turn around quickly. I think we will see the first new solar cell products based on our technology enter the market during the next five years.



Helge Weman, head of Nanordsun, hard at work in the laboratory. Photo: NordForsk/Terje Heiestad



CrayoNano: Nanowires on Graphene
www.youtube.com/watch?v=3wLOXHRVVwQ

Can win the race with China

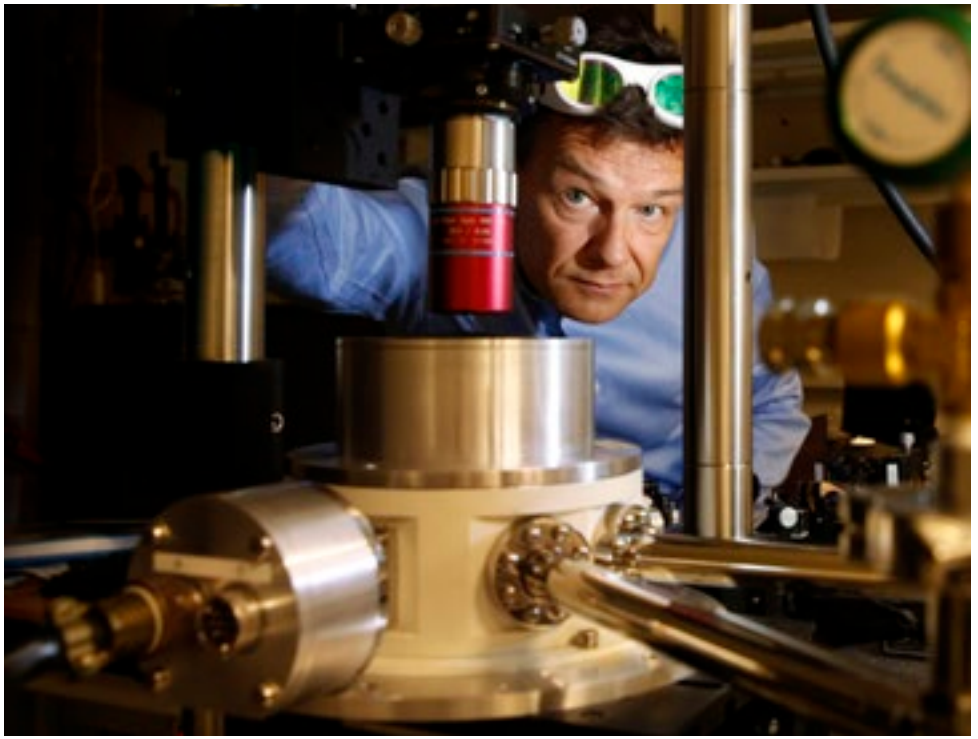
The Chinese almost managed to overtake the entire established solar cell market through a large-scale targeted initiative. But Dr Weman sees several reasons why the Nordic countries are in a strong position to win a solar cell race based on developments in nanotechnology. “Nanotechnology is a costly focus area. The Nordic countries are relatively wealthy and have the means to invest more in this area. We also have a flatter hierarchy, which means we are more receptive to new ideas. In Nordic research environments, new ideas can come from anyone, even doctoral candidates. This is much more difficult in Asia.

The greatest challenge we are facing is to reduce the cost of production of these new solar cells to keep them from becoming merely a niche product. “Our primary objective from this point onwards is to achieve high production efficiency, but we have to take it one step at a time,” Dr Weman states.

Motivated by the potential benefits

Anything that can improve the profitability of solar cells also helps in the campaign against global warming.

“It is especially exciting to work with this since we know how important this could be for the Earth’s climate. It’s hard work, but the thought of the myriad of benefits gives us extra motivation.”

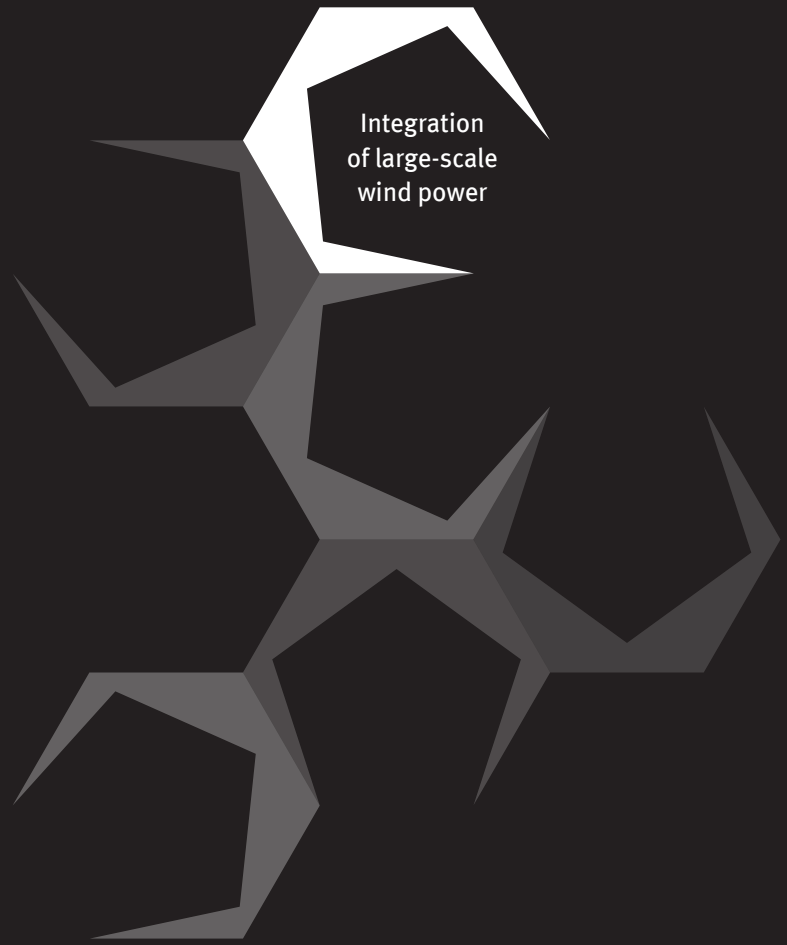


Helge Weman. Photo: NordForsk/Terje Heiestad

Integration of large-scale wind power

The vision of this subprogramme was:

- Promote the development of new, innovative and sustainable forms of wind energy and grid integration aspects.
- Create new constellations and co-operation platforms enhancing information exchange and transfer of knowledge between different stakeholders, such as researchers, business and policy makers.
- Optimise joint Nordic use of research and innovation infrastructure.
- Facilitate implementation of existing knowhow in society.


Integration
of large-scale
wind power

IceWind

Improved forecasting of wind, waves and icing

Winter Wind Farm. Photo: Doc_Steele/Getty Images


Integration
of large-scale
wind power

Forecasting icing, wind and waves

Wind turbines in the Nordic countries can become covered with ice, which can potentially reduce power output or damage the turbines. Researchers have now developed new tools for improved forecasting of icing, wind and waves.

The IceWind project, with partners from Denmark, Iceland, Finland, Norway and Sweden, focused on wind engineering in cold climates and some of the main challenges that can affect the Nordic offshore wind sector. It is generally a good idea to locate wind turbines in areas with a lot of wind, but it is a bad idea to locate wind turbines in areas with a high risk of icing in winter. Wind and icing tend to go hand in hand, but it is possible to find areas with more wind and less risk of icing. This requires a special-purpose atlas, and the researchers in the IceWind project rose to the challenge.

“We have developed a wind atlas and an icing atlas for Iceland and an icing atlas for Sweden, developed software that can help us predict icing, and studied integration of wind energy with the hydroelectric power system of Iceland. Another outcome is a set of recommendations on procedures and tools for the maintenance of offshore wind farms,” explains Niels-Erik Clausen, Senior Advisor at the Department of Wind Energy at the Technical University of Denmark (DTU).

The IceWind project addressed the challenge of large-scale integration of wind energy in the Nordic countries. The results of the project will be relevant for the public authorities and industry alike.

“The authorities can use our results when they are planning new areas for wind energy, and the industry can use our new tools in order to become more competitive and develop a higher export potential in the Nordic countries. The project will also be relevant in terms of making Nordic research in this field more attractive for large European projects, we think,” says Dr Clausen.

Senior Advisor Niels-Erik Clausen, Head of IceWind
Photo: NordForsk/Terje Heiestad

Project title: IceWind
Improved forecasting of wind, waves and icing

Project period: 2010–2014

Project partners: 13 partners from 5 Nordic countries

Website:
http://www.risoecampus.dtu.dk/Research/sustainable_energy/wind_energy/projects/VEA_Icewind.aspx

Left and above: Niels-Erik Clausen and Neil Davis (PhD) focused on wind engineering in cold climates and the challenges that can affect the Nordic offshore wind sector. Photos: Nordforsk/Terje Heiestad

Top: When wind turbines become covered with ice, there is a risk for reduced power output and damage to the turbines. Photo: Kent Larsson, ABvee

OffshoreDC

DC grids for integration of large-scale wind power

Most offshore wind farms, like this one outside Copenhagen, are built close to shore. Future wind farms further out at sea will need new technology for transmitting power to shore. Photo: Shutterstock


Integration
of large-scale
wind power

Direct current helps the climate

There is a limit to how much renewable energy can be produced in offshore wind farms with today's technology, partly because it is difficult to transport the energy over large distances across the ocean. "We are developing a new technology that should be more flexible and suitable for large wind farms far from shore," explains Nicolaos A. Cutululis.

Denmark, Germany, the United Kingdom and several other European countries have built a number of offshore wind farms in recent years, but most of them are located close to shore. In future, wind farms will be built further out because the best locations near the coastline are becoming overcrowded. However, this creates a host of new problems, which Nicolaos Cutululis and the partners in the TRI project Offshore DC are working to solve.

Today, most of the electricity from power plants both onshore and offshore is transmitted as alternating current (AC), where the flow of electric charge periodically reverses direction. In most of the Nordic countries, the charge changes direction 50 times per second. The "opposite" type is called direct current (DC), where the electric charge flows constantly in a single direction.

"The wall socket in your house delivers AC, but most of your home appliances run on DC. That is why there is a black box on the power cord to your laptop: it contains a rectifier that transforms AC to DC," explains Dr Cutululis.

Lost in transmission

The biggest problem with AC is that a lot of energy gets lost in transmission. It is possible to compensate for these losses with extra equipment along the line, which is what is done onshore. "But when you go offshore, everything is more complicated and expensive. For wind power a large distance from the coast, typically over tens of kilometres, it therefore makes more sense to use High Voltage Direct Current (HVDC) instead. While the technology has been around for over 50 years, its use offshore and in connection with large amounts of wind power is in the early phase. We are working on researching and developing this technology and proving that it is reliable," elaborates Dr Cutululis.

Another problem with offshore wind farms is that the power they deliver fluctuates with the wind. Fluctuations from a large-scale wind farm with a lot of turbines close to each other can be very extensive. According to Dr Cutululis, it is not easy to build a grid that can absorb the power from all these turbines and transmit it to shore economically and efficiently, but it is certainly possible. The young, enthusiastic team of PhD students at the heart of the OffshoreDC project is working very hard to make this a reality.

“We cannot fully prove the reliability of HVDC grids in our project because most of our work is about building theoretical models and computer models that can be used for simulations. At the same time, the close involvement of the industry ensures that this knowledge is aligned with and will be transferred to the industry. The overall objective of the project is to identify and pursue solutions to offshore HVDC grids and their functionality as a means of integrating large amounts of offshore wind power. The project is running to 2016, so a lot of our results will come later. We are in fact entering the most interesting period as we speak. The big picture is of course that we are trying to develop HVDC as a contribution to saving the global climate,” concludes the project leader.

Senior Researcher Nicolaos A. Cutululis, Head of Offshore DC
Photo: Berit Carius Larsen/DTU

Project title: OffshoreDC
DC grids for integration of large-scale wind power

Project period: 2011–2016

Fellowships: 6 PhDs, 1 Post-doc

Project partners: 10 partners from 5 Nordic countries

Website: www.offshoredc.dk

OSR Nordic

Optimal Spinning Reserve of Power Systems Considering Forecasting Error of Load and Wind Power Generation under Market Environment

Wind turbines such as these at the Anholt Offshore Wind Farm in the Kattegat sea have rotor blades that can change angle to adjust energy output as needed. Photo: t-lorien/Getty Images


Integration
of large-scale
wind power

Smart to keep reserve energy ready

Energy producers do not maximise their earnings if they generate at full capacity all the time. This is because electricity markets also need a reserve capacity that can kick in at short notice. This reserve is bought and sold according to complex calculations.

Although few people think about it as they switch their appliances on or off, the total electricity being produced within a system always needs to match consumption. Energy producers must therefore constantly adjust their output up or down as consumption rises and falls in the course of each day and throughout the year.

"Currently, about one-third of the electricity produced in Denmark comes from wind turbines, and the target is to boost this up to half by 2020," explains Associate Professor Birgitte Bak-Jensen of Aalborg University. "Energy production from wind turbines depends, of course, on how much wind is blowing, so on calm days more electricity has to come from our other energy sources, such as hydropower facilities, thermal power stations and gas turbines. This is how it is in any country that gets its energy from multiple sources."

Spinning reserve is needed

"Energy producers and distributors know roughly how consumption will vary throughout the day and seasonally, but precise amounts are difficult to predict," continues the associate professor. "Furthermore, disruptions do occur now and then, for instance if a large power station needs to be shut down. For this reason, energy producers must maintain a spinning reserve that can be brought into play at short notice."

Associate Professor Bak-Jensen led the TFI project OSRNordic, where the goal was to determine the system-optimal spinning reserve by considering probabilistic forecasts of wind power, load and electricity price in order to minimise total system production cost. The researchers also investigated the effect of energy storage on the above factors.

Two markets for the same energy

In principle, energy producers could enter into agreements to sell all the electricity they are able to produce all the time, but that would leave them with no reserve energy to sell, and they would risk penalties if their production were to fall short of contractual amounts. This is why it is so essential to have access to the most accurate predictions possible for both demand and reserves.

"The big question," says Dr Bak-Jensen, "is how large spinning reserve must be to ensure that the system has adequate but not excessive reserves. In this project we developed enhanced analytical methods to predict the size of fluctuations in both energy production and demand for spinning reserve."

Associate Professor Birgitte Bak-Jensen, Head of OSRNordic
Photo: Aalborg University

Project title: OSRNordic
Optimal Spinning Reserve of Power Systems Considering Forecasting Error of Load and Wind Power Generation under Market Environment

Project period: 2010–2013

Fellowships: 2 PhDs, 3 Post-docs (part-time)

Project partners: 7 partners from 3 Nordic countries

Spinning reserve defined

Spinning reserve is defined as the extra generating capacity that is available by increasing the power output of generators already connected to the power system. For most generators, this increase in power output is achieved by increasing the torque applied to the turbine's rotor.

Sustainable bio-fuels

This programme focused on more advanced forms of biofuels that do not compete with food crops.
The overarching objectives of the programme were:

- to promote the development of new, innovative and sustainable forms of biofuels
- to enhance the development of Nordic R&D institutions and businesses in the field

The programme aimed to improve the utilisation of existing resources, while focusing on
bio-based fuels for transport from lignocellulose and cellulose based biomass.
This included agricultural, industrial and domestic waste.


Sustainable
bio-fuels

BioEng

Production of second-generation biofuel and its influence on engine combustion and emissions

Waste timber in a Finnish forest. Photo: Kichigin/Shutterstock


Sustainable
bio-fuels

Testing sustainable biofuels in state-of-the-art engines

First-generation biofuels are made from sugars and vegetable oils found in food crops, a practice which can be seen as competing with food production. Second-generation biofuels are more sustainable because they are made from waste material. A group of researchers in the BioEng project is investigating how engines must be adapted in order to burn the new fuels.

Second-generation biofuels can be made from resources such as lignocellulosic biomass or woody crops, agricultural residues or waste. This makes them more sustainable than first-generation biofuels, but with the downside of being derived from harder-to-extract raw materials. The new fuels also differ from both conventional petroleum fuels and first-generation biofuels in the ways they affect engine combustion, performance and emissions.

“In this project we have studied the effect of second-generation biofuels in state-of-the-art engines. We have done experiments in a test facility and matched them with computer-based simulations of the combustion and emissions,” explains Professor Terese Løvås of the Norwegian University of Science and Technology (NTNU).

Two fuel types tested

The researchers tested two kinds of fuel. One was produced through the Fischer-Tropsch process, which can be used to make diesel fuel from raw ingredients such as coal and biological waste. The other fuel tested was dimethyl ether (DME) gas, supplied by a Swedish company that utilises by-products from the wood processing industry.

“Both fuels, but particularly the Fischer-Tropsch diesel, can have different compositions depending on the raw materials they are produced from,” says Professor Løvås. “In practice this means that engines need to be adapted to run on them, and that the combustion emissions can vary.”

Trials so far show that emissions of NOx and particulate matter from engines run on second-generation biofuels can be lower than with conventional fuels, but that this requires engine modifications such as injecting the biofuel into the cylinder a split-second earlier.

“This will be a dilemma for the automobile manufacturers,” explains Professor Løvås. “Should they build engines that can only run on special types of biofuels, or build ‘smart’ engines that can adjust automatically to different fuels? In the latter case, the automakers will need to figure out how an engine can analyse combustion and adjust accordingly.”

Professor Terese Løvås, Head of BioEng project
Photo: NordForsk/Terje Heiestad

Project title: BioEng
Production of second-generation biofuel and its influence on engine combustion and emissions

Project period: 2011–2014

Fellowships: 1 PhD, 1 Post-doc

Partners: Seven partners from Nordic countries and Germany

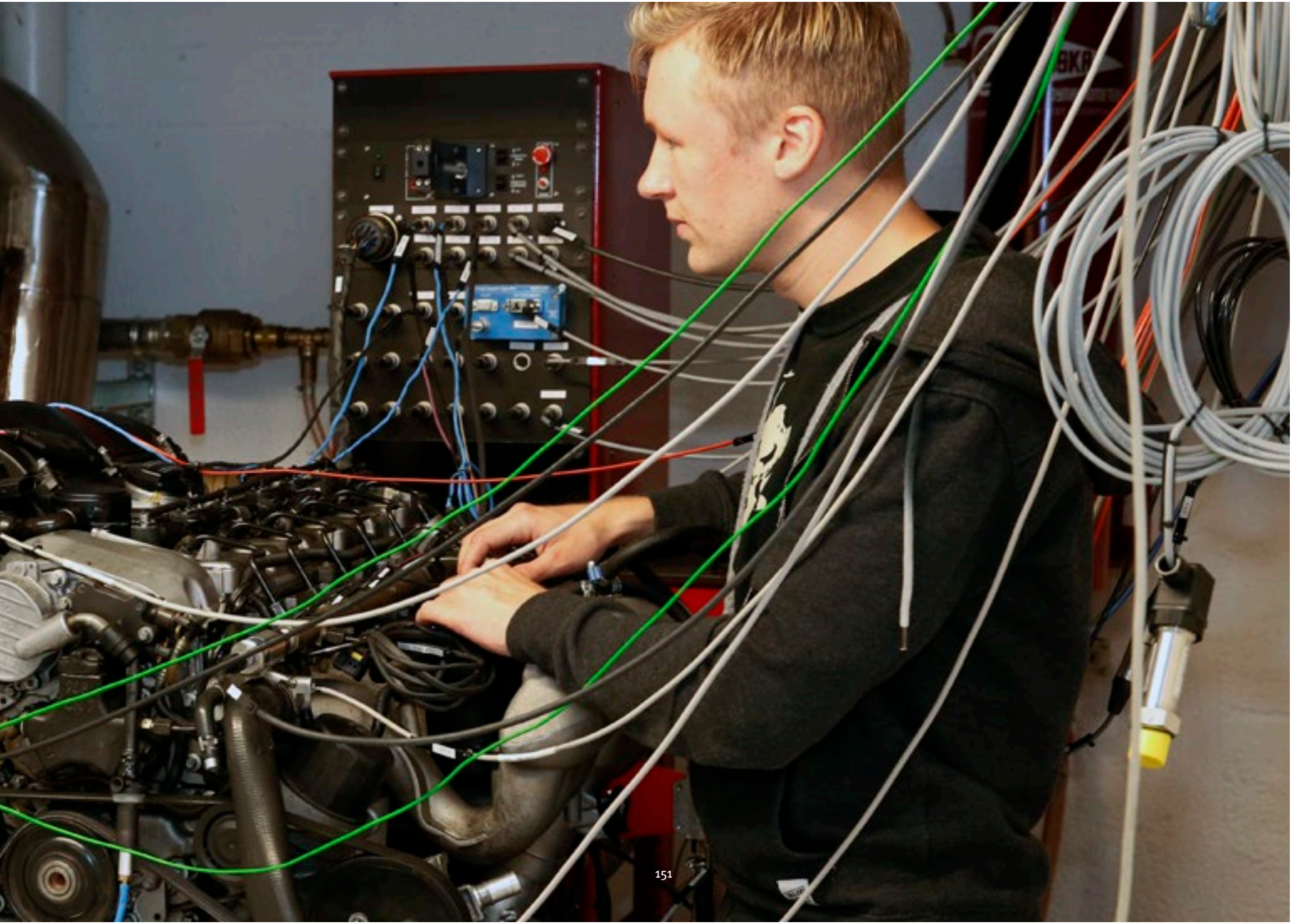
Website:
http://www.toppforskningsinitiativet.org/no/programmer-1/program-5/prosjekter/prosjekt-4

Total emissions of particulate matter could be reduced by using second-generation biofuels, but the project researchers have also found that these particles may be finer. “Smaller particles may pose a greater health threat when inhaled,” she cautions, “so this should be investigated more closely.”

Greater understanding

“In this project we have specifically developed digital models that predict the combustion conditions in an engine that result in the different emissions, along with actual lab measurements. The project has led to a greater understanding of how we can reduce emissions, especially of particles and nitrous oxides from engines running on different kinds of biofuels,” explains Professor Løvås.

Not surprisingly, Volvo, Saab and Ford all took part in the project. The researchers also cooperated with industrial partners that produce biofuels, and others that develop software for simulating combustion in engines. This has created a platform for a more sustainable production and use of second-generation biofuels in the future.



Professor Terese Løvås and Engineer Stein Kristian Skånøy. Photo: NordForsk/Terje Heiestad

SusBioFuel
Innovations in Bioethanol Production Technologies

Producing bioethanol from straw and softwood (pictured) is a multi-stage process. Photo: Przemyslaw Wasilewski/Shutterstock


Sustainable
bio-fuels

Large strides towards profitable bioethanol

A Nordic research group has been studying and improving every stage in the complex process of converting straw and softwood into bioethanol – but more research is still needed to make the conversion process profitable.

The EU has set a target for 10 per cent of all its transport sector energy consumption to come from renewable sources by 2020. Norway, Sweden and Denmark are aiming to have transport sectors that are completely free of fossil fuels by 2050, while Iceland and Finland are looking to reduce fossil fuel consumption by 50–70 per cent and 80 per cent, respectively. One measure that can help make it possible to reach these targets is to increase the proportion of biofuel in diesel and petrol. But more research is needed before a level of even 10 per cent of energy consumption from renewable sources can be achieved.

There are basically three kinds of biofuel: biodiesel, bioethanol and biogas. The climate footprint of biofuel varies according to the biomass used in its production, and how that organic matter is grown and then processed into biofuel, and it is important to avoid cultivating biomass that competes with food production. Straw and softwood are thus among the best alternatives.

High cost is currently the biggest obstacle to using straw and softwood for producing bioethanol. A research group headed by Research Scientist Sidsel Markussen of SINTEF Materials and Chemistry has examined all the processing stages in converting straw and softwood into bioethanol closely and has identified the bottlenecks that are slowing development.

The problems are solvable

"Under this project we have pinpointed some of the technical problems that need solving before the conversion process can be made profitable," says Ms Markussen. "We have also determined that there are no unsolvable problems within this process."

Producing bioethanol from straw and softwood is a multi-stage process, as Ms Markussen describes:

"Stage one is to break down or deconstruct the raw materials in order to separate out the components for the following stages. First and foremost we need to get to the cellulose. Stage two is an enzymatic process that breaks the complex cellulose molecules into simple sugars. Next comes the fermentation stage, which converts the sugars into ethanol and some by-products, and finally we need to separate out the ethanol from this mixture."

Research Scientist, Sidsel Markussen, Head of SusBioFuel
Photo: Private

Project title: SusBioFuel
Innovations in Bioethanol Production Technologies

Project leader until August 2014: Nils Dyrset, Senior Research Scientist, SINTEF

Project period: 2011–2014

1 PhD, 1 Post-doc
8 partners from five Nordic countries

High cost is currently the biggest obstacle to using softwood (pictured) and straw for producing bioethanol. Photo: somchaiP/Shutterstock

The Paper and Fibre Research Institute (PFI) in Trondheim has been focusing on the first stage and has among other things studied methods for reducing the lignin content in the wood of Norway spruce trees. This experiment successfully yielded cellulose accessibility of as much as 75–85 per cent.

Researchers at the Technical University of Denmark in Copenhagen have been working in parallel on improving the subsequent enzymatic process. Among other things they have developed a new recycling technique based on immobilising the enzymes on the surface of tiny magnetic particles. The technique allows the enzymes to be magnetically separated from the mixture and then recycled to perform their job repeatedly, thus reducing enzyme costs.

Mutant bacteria working for the climate

The research institute Icelandic Food and Biotech R&D (Matís) has been developing thermophiles (microorganisms that grow optimally at high temperatures) that are well-suited for use in bioethanol production. This is done by isolating multiple new strains of bacteria and by genetically modifying existing strains.

“One of our results,” continues Ms Markussen, “is that we now have what are called double-mutant bacteria that no longer have the enzymes needed to produce acetate and lactic acid. These bacteria therefore produce more ethanol instead. But anyone who has tried to make wine at home knows that the yeast die when the concentration of ethanol becomes too high, and this is also the case with bacteria used to produce bioethanol. So we have been working on methods to remove the ethanol from the mixture as it is produced, and to make the bacteria more resistant to ethanol.”

“In my opinion we have accomplished a great deal under this project. Together, the participating research groups from five Nordic countries have achieved improvements at every stage of the production process and identified important areas for further research and development. In addition we have ascertained, from an economic perspective, where the bottlenecks are. It turns out that the first stage, separating out the cellulose from the biomass, is currently the largest factor limiting bioethanol production from being profitable. In other words,” Ms Markussen summarises, “we are now closer to a profitable process, but we’re not at the finish line yet.”

Cellulose

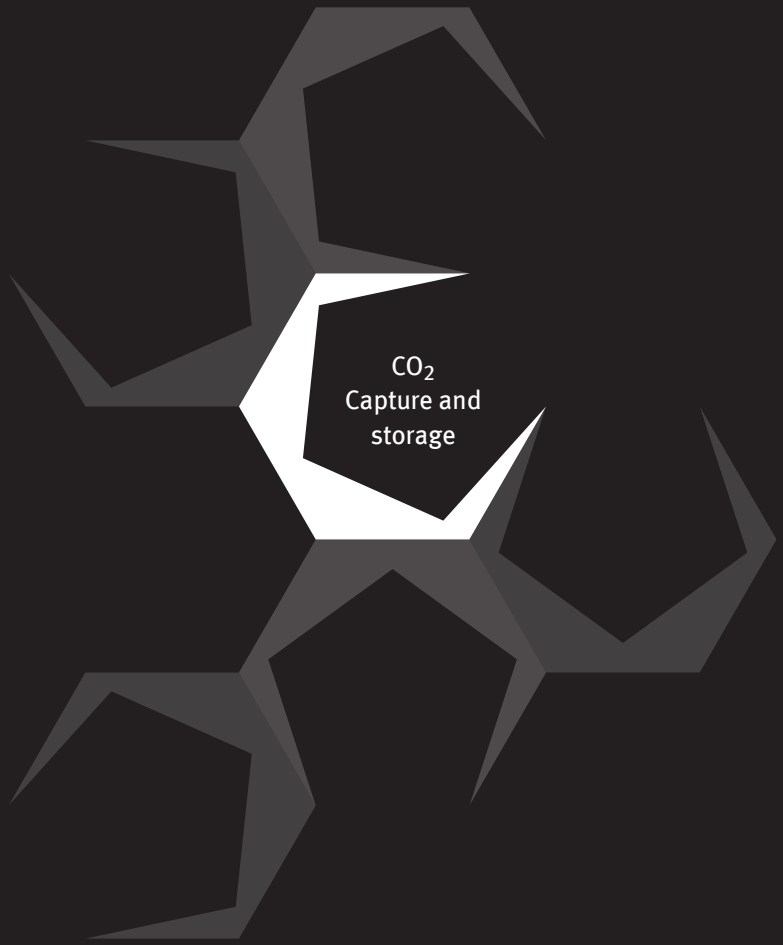
Cellulose is a polysaccharide, meaning that its molecules are composed of long, linear chains of carbohydrates (Beta-glucose units) bound together. Chain length varies from a few hundred to tens of thousands of units. Cellulose is the most abundant organic polymer on Earth. It is produced by plants, algae, certain bacteria and tunicates (a marine subphylum of marine invertebrates), but the main source of cellulose for industrial purposes is plant material. Roughly 50 per cent of softwood is cellulose. (Source: Wikipedia)

CO_2 – Capture and Storage

The objective of the sub-programme was to facilitate cooperation between industry, researchers and policy makers.

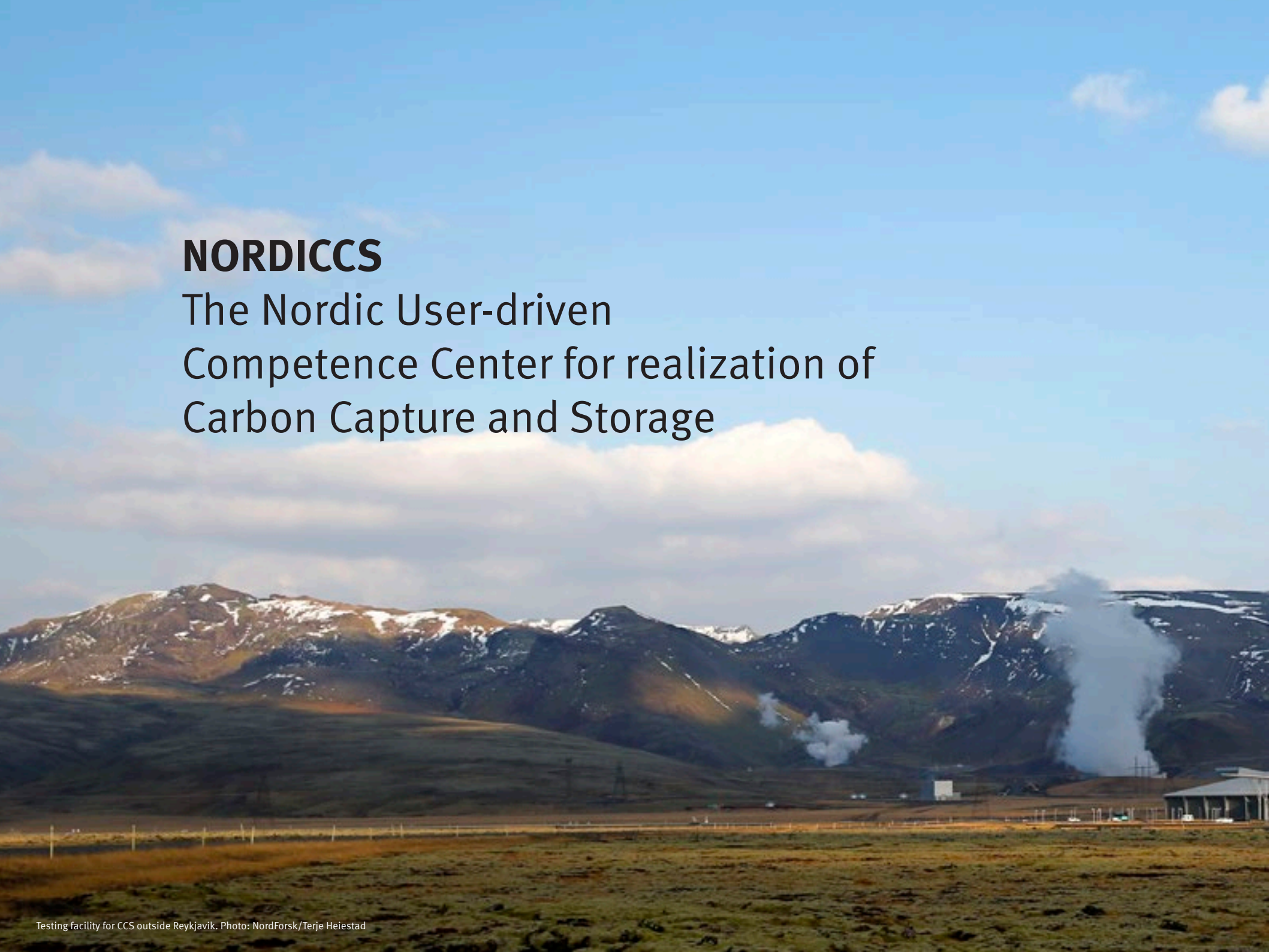
Two studies on ongoing national activities and priorities were prepared in the start phase of the sub-programme. VTT Technical Research Centre of Finland made an overview of the technologies and applications required for CCS in the Nordic countries. Sund Energy's (Norway) study focused on the role of Nordic CCS in a renewable scenario.

The Nordic User-driven Competence Center for realization of Carbon Capture and Storage (NORDICCS) was established in 2011 and funded until 2014, as a virtual networking platform aiming for increased CCS deployment in the five Nordic countries. The objective of NORDICCS was to boost the deployment of CCS in the Nordic countries by creating a durable network of excellence integrating R&D capacities and relevant industry.


CO_2
Capture and
storage

NORDICCS

The Nordic User-driven Competence Center for realization of Carbon Capture and Storage



Testing facility for CCS outside Reykjavik. Photo: NordForsk/Terje Heiestad


CO_2
Capture and
storage

“Climate targets cannot be met without CCS”

Global, EU and Nordic climate targets cannot be met without carbon capture, transport and storage (CCS). Between 20 and 30 million tonnes of CO_2 must be captured and stored annually by 2050 in the Nordic countries, according to the new Nordic CCS Roadmap.

The Nordic countries are planning to stop using fossil fuels for power generation by 2035 in order to cut CO_2 emissions and take an important step towards safeguarding the global climate. The new Nordic CCS Roadmap, however, makes it clear that additional, comprehensive measures will be needed if climate goals are to be met. Carbon capture, transport and storage (CCS) is the only technology which can substantially reduce CO_2 emissions from fossil fuels, especially when it comes to industrial emissions and carbon negative solutions, bio-CCS, which combines large-scale bioenergy and CCS.

Three key findings

“We have mapped the largest point sources of CO_2 emissions in Norway, Sweden, Denmark, Finland and Iceland, and it is clear that the Nordic region’s largest anthropogenic emissions come from industry,” says Nils Anders Røkke of the independent research foundation SINTEF in Trondheim. “Companies that produce steel, cement or pulp, for instance, have few options other than CCS for substantially cutting their CO_2 emissions. Therefore we must implement this technology large-scale if the Nordic countries are to achieve their climate goals.”

Dr Røkke is SINTEF’s Vice President for Climate Technologies as well as Director of the Nordic CCS Competence Centre (NORDICCS), which was established under the Top-level Research Initiative. NORDICCS is a virtual CCS competence centre providing a research and innovation platform with leading partners from all the Nordic countries. Industrial partners include Statoil Petroleum AS, Norcem AS, Gassco and Vattenfall AB. For a complete list of the centre’s industrial and research partners, visit the NORDICCS website.

“The three main results of NORDICCS’ efforts so far are: We have mapped the possibilities for storing CO_2 in the Nordic countries, we have drawn up a roadmap showing how our countries can work towards CCS in the years ahead, and we have shown how to link the CO_2 point sources and storage sites together with an integrated Nordic transport system,” explains Dr Røkke.

Large-scale emissions and storage capacity

The roadmap shows that Sweden and Finland in particular have many sites that are major CO_2 point sources. At the same time, Finland lacks the type of geological formations that can store the greenhouse gas, while Sweden has some minor storage potential in the Baltic Sea. However, there are substantial opportunities for storage in the North Sea off the

Nils Anders Røkke, Head of NORDICCS
Photo: NordForsk/Terje Heiestad

Project title: NORDICCS
NORDIC CCS Competence Centre

Project period: 2011–2015

Project partners: 17 partners from five Nordic countries

Website:
http://www.sintef.no/Projectweb/NORDICCS

coasts of Norway and Denmark. CO_2 can be stored in deep, water-bearing geological layers, where the gas eventually dissolves into the water and then reacts chemically with the rock to mineralise. In addition, Icelandic researchers have developed a novel method to mineralise CO_2 in volcanic basalt formations (see related article).

So, the Nordic countries as a whole produce large CO_2 emissions but also have large-scale possibilities for storage. What they lack is a transport system that can connect the CO_2 point sources and the storage sites.

"Previously most of the focus was on pipelines for transporting CO_2, but our work has shown that transport by ship is a competitive solution for our region. This can be combined with using central hubs for further transport in pipelines where conditions allow. Thus we envision the construction of terminals that receive CO_2 from industrial companies that are major point sources, then the CO_2 is freighted by specially outfitted ships to the North Sea storage sites," explains Dr Røkke. "This is a feasible concept given the right incentives".

The technology exists

Much of the technology needed to accomplish CCS already exists. As far back as 1996, the Norwegian petroleum company Statoil began injecting CO_2 into a geological formation 1 000 meters beneath the seabed at the Sleipner field in the North Sea. Statoil also started a similar project at the Snøhvit field off Hammerfest, Norway, in 2008. The two projects are now storing roughly 1.7 million tonnes of CO_2 between them annually.

"There is nothing new about transporting CO_2 by ship either," continues Dr Røkke. "The industrial company Yara has several years' experience in exporting pure CO_2 from its ammonia production in Porsgrunn, Norway, to breweries and food producers in Europe."

Moreover, large quantities of CO_2 are used during Enhanced Oil Recovery (EOR) onshore in the USA and Canada. The technique pumps CO_2 gas into petroleum reservoirs under high pressure in order to increase recovery rates of oil and gas. So far only small-scale EOR offshore has been attempted.

Network for CO_2 transport and storage

The NORDICCS centre recommends establishing a Nordic network of "trunklines" for transporting and storing CO_2.

"It is a given that this is infrastructure where the national governments would have to assume a significant share of the investment, as they do with funding roads and power lines, for example. The next step is therefore to scale up to large, integrated demonstration projects, with the potential to drive costs down – from both technology improvements and economies of scale," says Dr Røkke.

Estimates indicate that vast amounts of CO_2 – a total of 150 billion tonnes – could be stored in the North Sea.
"To put this in context," adds Dr Røkke, "Norway's annual emissions are roughly 50 million tonnes. The North Sea has enough capacity to function as a permanent storage site for CO_2 from all of Europe's point sources for the next 50 years."

Atmosphere of trust

The vision of a pan-Nordic CCS infrastructure cannot be realised without know-how, so the NORDICCS centre has

established a summer school for Nordic doctoral students interested in concentrating on one of the chief climate technologies of the future. The week-long session is held every other year, with roughly 30 students. Among other activities they visit the Technology Centre Mongstad (TCM) north of Bergen.

Students earn academic credits through the course by completing a specific assignment. One of the assignments in 2013, in fact, was to draw up a proposal for a Nordic CCS roadmap.

"In addition to having developed new knowledge about CCS, this project has taught us quite a bit about the value of Nordic cooperation," says Dr Røkke. "What works so well between the Nordic countries is that we have the necessary control mechanisms in place, and not more than that! Nordic cooperation is characterised by an atmosphere of fundamental and mutual trust. This runs so deep that each country puts its research allocations into a common Nordic pot, and no one demands exactly fair splits when the funds are allocated to research projects in the various countries. This promotes efficient use of the funds allocated to Nordic research. In the EU system, by comparison, there is more control and less trust, which slows down the entire machine."

Dr Røkke is now looking to continue the activities of the NORDICCS centre under the funding programme Nordic Flagship Projects, announced by Nordic Energy Research in autumn 2014. This programme is the largest and most important joint Nordic funding programme for energy research for the next four years. Under the call NOK 80 million is available to support three to five Flagship Projects for up to four years each.

Lab at SINTEF. Photo: NordForsk/Terje Heiestad

Carbon Capture and Storage (CCS)

Carbon capture, transport and storage is the process of capturing waste carbon dioxide (CO_2) from large point sources, such as fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere, typically in an underground geological formation. The aim is to prevent the release of large quantities of CO_2 into the atmosphere.

“Quick fix” turns CO_2 into rock

Good news for the global climate: a group of researchers on Iceland has developed a “quick fix” that turns CO_2 into rock. Between 80 and 90 per cent of the CO_2 turns into stable carbonates within a year after injection into porous basaltic lava formations.

Several research groups have studied solutions for carbon capture and storage (CCS) based on injection of the gas into depleted petroleum reservoirs or sedimentary basins below impenetrable cap rocks. Underground carbon storage using these procedures eventually leads to the conversion of CO_2 into stable minerals in a natural process that takes thousands of years. But what if the cap rock leaks and the CO_2 escapes into the atmosphere before it has been stabilised?

CO_2 becomes rock in a year

A group of engineers and scientists on Iceland have revealed that there is high potential for mineral storage of CO_2 in Icelandic volcanic rock, also called basalt. The project has developed a “quick fix” for underground carbon storage which drastically reduces the time needed for mineral carbon trapping.

“We don’t have sedimentary basins with cap rocks in Iceland, so we came up with another idea. Instead of injecting the gas into underground reservoirs, we are dissolving the gas in water. This creates an acidic fluid, which is pumped down into the porous basaltic lava formations that are common on Iceland. The fluid dissolves the primary host rock, and this again leads to the release of iron, magnesium and calcium that is present in the basalt. These elements can then react with the CO_2 and form minerals called carbonates. In other words: the CO_2 is turned into rock,” says Edda Sif Pind Aradóttir.

“Our results show that between 80 and 90 per cent of the injected CO_2 turns into carbonates within a year,” adds Dr Aradóttir. She is a reservoir engineer at Reykjavik Energy’s Department of Geothermal Research and earned her PhD in chemistry and reservoir engineering at the University of Iceland in 2011.

Stable over geological timescales

Dr Aradóttir explains that the carbonates are stable over geological timescales, so there is no need to worry about the release of CO_2 into the atmosphere again. There is a lot of basalt in the world, so the method holds great international potential.

“About 10 per cent of the continents are covered with basalt. There is also a lot of basaltic rock on the oceanic ridges and the oceanic floor, so the global capacity for CCS in basaltic

Edda Sif Pind Aradóttir stores CO_2 in porous basaltic lava. Photo: NordForsk/Terje Heiestad

rocks is very large. We have so far only used fresh water in our field injections, but seawater used in laboratory studies has demonstrated the same potential as fresh water," she says.

The researchers performed their first pilot injection in 2012 and have been monitoring the results ever since.

"The higher the content of iron, magnesium and calcium in the basalt, the faster the mineralisation occurs," explains Dr Aradóttir.

She believes that there is probably a limit to how much CO_2 can be stored underground in rock, but that limit is far away. "This method can be used wherever you have the three important components: a CO_2 source, the basaltic rock, and water for dissolving. I am convinced that this technology can contribute to a very significant reduction in the global emissions of CO_2," she says.

The Icelandic way

The idea was first presented at a roundtable conference on Iceland in 2006. This gave rise to the CarbFix project featuring Icelandic and international partners in 2007.

"Originally, some of the other NORDICCS partners were sceptical to the 'Icelandic way' of carrying out CCS. Over the past years, however, our understanding of the process has increased, and our method has become a viable solution towards fighting climate change. The grant from the Top-level Research Initiative has contributed to this by financing a PhD student at the University of Iceland," concludes Dr Aradóttir.

The testing facilities outside Reykjavik sits above thick layers of basaltic rock. Photo: NordForsk/Terje Heiestad

Evaluations and comments

“The Top-level Research Initiative in itself has been a success. Nordic cooperation has functioned very smoothly, and the initiative has already resulted in a number of interesting findings. However, it is too early to say what the final research results will bring – we will have to wait several years,” says Rolf Annerberg.

Photo: NordForsk/Terje Heiestad

The Top-level Research Initiative is a success

Rolf Annerberg has been Chair of the Management Board of the Top-level Research Initiative (TRI) since the initiative was launched in 2009. There were many who were glad that it was precisely this experienced Swedish research administrator who shouldered the responsibility for this major task.

"This is the largest-ever research programme conducted in a Nordic context, and a flagship initiative launched by the Nordic Prime Ministers," said Mr Annerberg in an interview when he assumed his position in 2009. There is pressure to deliver results when five Prime Ministers have allocated a total of DKK 400 million, and now, five years down the line he can breathe a little easier as he notes that, for the most part, the expectations have been satisfied.

"The initiative has functioned well. It has given us good examples of Nordic flexibility and cooperation. New opportunities have opened up for the researchers participating in the initiative – within and outside the Nordic region, not least in the EU. The researchers have also carried out top-notch projects that are generating important results," he says. Many of these results are described in this book.

TRI was a stamp of quality

"The results have been good due in part to the tough competition for funding under the TRI. Being chosen to participate was evidence that the researchers were carrying out work of the highest international standard. I have met many researchers who told me that TRI status has made it easier to build networks with researchers in other countries because their new partners recognised the TRI as a stamp of quality," explains Mr Annerberg.

The greatest divergence from the original expectations is actually related to the political follow-up.

"When we started out in early 2009, we were hoping that the initiative would make it easier to reach an agreement at the UN Climate Change Conference in Copenhagen in December of that same year. But the conference was not a success, for various reasons. We didn't manage to achieve our political goals in the short term, but perhaps they weren't that realistic. In any case, the TRI has still been a successful, highly important initiative. It has generated a lot of new knowledge about ongoing climate change and how we can deal with the major challenges facing us," he says.

Climate research also needs social scientists

The TRI also sought to integrate the social sciences and humanities into all segments of the initiative, which had a natural science approach as its point of departure.
The Norwegian sociologist and former government minister Gudmund Hernes wrote an important report for the TRI, in which, among other things, he points out that climate scientists, meteorologists and oceanographers have provided a wealth of new knowledge. But as Dr Hernes states, "this is not enough because knowledge in itself is never a sufficient basis for action." Dr Hernes therefore recommends mobilising the social science disciplines (see page 180).

"Our expectations in this area haven't been 100% fulfilled either, but integration has nevertheless worked well in many of the programmes," says Mr Annerberg.

Unique multinational cooperation

"I have found that when we speak to researchers outside the Nordic countries about Nordic research cooperation in general terms – with the TRI as the prime example – many of them are curious as to what we have done to be so successful. The initiative is a unique example of collaboration across national boundaries, and is made possible by the high level of trust between the individual Nordic countries. We also have a tradition of cooperation, and we are, after all, relatively few partners. Thus we can achieve what other multinational regions can only dream of," says the Management Board Chair. Although the initiative is drawing to a close, Mr Annerberg believes that it will live on as a model for multinational cooperation.

"If Nordic political leaders in the future should wish to establish a corresponding initiative in another area, we now know how it can be organised. We also know how to design the initiative to be effective. Thus we can be secure in the knowledge that a potential new initiative will also deliver important, interesting research findings," he concludes.

Rolf Annerberg

He holds a Politices magister degree, and has been a director general, top-level official and political actor in the Social Democratic party in Sweden. Mr Annerberg was State Secretary for energy issues at the Ministry of Enterprise and Innovation (current name) (1984–1987), the Ministry of the Environment and Energy (1987–1990) and again at the Ministry of Enterprise and Innovation (1990–1991). After the victory of the Moderate Party in 1991, he moved to the position of Director General of the Swedish Environmental Protection Agency (1991–1999).

Mr Annerberg was also the board chair of the Swedish Foundation for Strategic Environmental Research (Mistra) (1997–2000). He served as the Chief of Cabinet for European Commissioner Margot Wallström from 2000–2006, and was thereby her closest colleague. Mr Annerberg held the position of Director General of the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas) from 2007–2013. Today he is a special advisor to the Swedish Government.

The Top-level Research Initiative Management Board is comprised of 15 members from the five Nordic countries. The members represent public financing bodies for research and innovation, as well as the private sector. The board appointed programme committees for the six different sub-programmes.

Top-level Research Initiative – a political priority

The Top-level Research Initiative (TRI) was established at a time when climate change was high on the agenda, not least in connection with the UN Climate Change Conference in Copenhagen in 2009 (COP15). It was important for the Nordic countries to stand together and formulate a common basis for the climate negotiations.

"The TRI emerged within this context, and it was highly relevant then as it still is now. The five Nordic Prime Ministers recognised that the Nordic countries shared common interests on the issue and that we would stand stronger if we were united. This was a unique opportunity for Nordic cooperation to achieve something of high quality, at a top scientific level," says Dagfinn Høybråten, Secretary General of the Nordic Council of Ministers.

In his view, this type of Nordic cooperation should be more widely practised because it addresses many of the aspirations that the governments have for cooperation in the future:
achieving synergy through proximity;
drawing international attention to the Nordic countries;
producing and developing the basis for solutions to large-scale, global issues.

Nordic research programmes are not usually initiated at the highest political level, as was the TRI.

"The countries acted together in using research to address a specific, critically important area. Nobody wants purely political initiatives, but there may be reason to pause and consider the TRI and ask what we can learn from it. If we face a major new challenge in the future, we cannot rule out that a similar model would be used again."

Exceeded expectations from a scientific perspective

Five years have passed since the TRI was established, and the benefits of the initiative can be clearly seen at many levels. Although the programme period formally concluded in 2014, a number of projects and activities will continue, and the final results will not emerge for several years.

"A thorough follow-up evaluation has been conducted, and the conclusions are overwhelmingly positive, with many good results," says Mr Høybråten. Important examples he highlights include the large degree of cross-disciplinarity and high scientific quality, also seen in an international context. Publication and widespread distribution of articles as well as a strong focus on communication and dissemination are also key achievements mentioned in the evaluation.

Dagfinn Høybråten in Greenland. Photo: Norden.org

Dagfinn Høybråten in Greenland. Photo: Marianne Neraal/Norden.org

In addition, the Secretary General emphasises that the TRI clearly shows, both within and outside the Nordic region, that the Nordic countries are strong when they stand together. The Nordic governments had a clear expectation that the initiative would help to give a clearer profile to Nordic research cooperation and produce applicable results.

“The TRI has had strong political support, and we see that much has been accomplished in a short period of time, perhaps even beyond our expectations,” he says.

Predecessor to modernisation and reform

Nordic cooperation is currently undergoing a modernisation and rationalisation process that focuses on results and added value.

“The TRI can definitely be viewed in the spirit of the reform. Some elements of the initiative correspond directly with the reform, such as greater cross-disciplinarity and joint knowledge development in which the results are made more applicable and applied more often. These are two sides of the same coin. And we are looking to create a framework for political action based on knowledge. This is also addressed in the Nordic Council of Ministers’ project on open access, in which all kinds of projects and the large number of publications produced within the totality of Nordic cooperation are being made searchable and easily accessible for application and further use.”

Continuation in new initiatives

The TRI is a cooperative effort across the Nordic countries as well as outside the region, and puts the spotlight on a scientific arena.

“Our research cooperation makes the Nordic countries more visible internationally,” says Mr Høybråten, and the TRI addresses research question that remain critical even though the initiative is coming to a close.

“The TRI is part of a set of topics that also includes green growth and the bioeconomy. These topics will be high on the Nordic political agenda in the years to come,” concludes the Secretary General.

Top-level Research Initiative has advanced Nordic research

The Top-level Research Initiative (TRI) has produced important scientific results and provided a major contribution to the Nordic research effort in the areas of climate, energy and the environment. This is the main conclusion in the final evaluation by the independent consultancy firm DAMVAD.

The TRI has been subject to ongoing review by the independent consultancy firm DAMVAD through a formative evaluation project launched in spring 2010. An interim evaluation in 2011 showed that the Top-level Research Initiative was a well-functioning research and innovation programme that had generated a relevant portfolio of promising projects. The final evaluation was completed in autumn 2014. Many publications, high impact factor

The final evaluation now documents the many positive results that were achieved. It shows, for instance, that the number of scientific publications by the participating researchers has risen in the past four years and particularly in the year from 2012 to 2013. Publication levels will continue to increase for several years into the future, in part because many of the projects are not yet concluded.

Just as important is the fact that the citation frequency and the scientific journals' impact factor are high. The evaluation shows that 31 per cent of the articles are published in the most influential journals, which is considerably higher than the 20 per cent that was expected.

Interdisciplinary research

One of the primary objectives of the TRI was to support or stimulate interdisciplinary research, and this has been achieved. The final evaluation shows that more than 70 per cent of all the scientific articles by the TRI researchers are published in interdisciplinary journals. Moreover, 66 per cent of the published articles have non-Nordic authors in addition to Nordic authors. Many of the participating researchers emphasise that they have benefited greatly from dialogue and cooperation with researchers in other areas of the TRI that study climate issues from a variety of scientific perspectives.

Productive cooperation

One of the lessons learned from the TRI is that the Nordic countries have the ability to reach consensus and establish a large-scale programme in a relatively short period of time.

If Nordic research cooperation is to once again be given higher priority on the Nordic political agenda, an effort should be made to identify areas where there is a comprehensive need for action – similar, for instance, to how the threat of climate change was seen in 2007.

In particular, the evaluation mentions NordForsk's programme "Responsible Development of the Arctic: Opportunities and Challenges – Pathways to Action" and the new Nordic Centre of Excellence programme on health and welfare research. The evaluation states that both of these address topics that are highly relevant in a joint Nordic context, and both are attracting a great deal of political attention.

A third area is the "Green Growth – The Nordic Way" initiative established by the Nordic Prime Ministers and administered under the auspices of the Nordic Council of Ministers. The three organisations – NordForsk, Nordic Energy Research and Nordic Innovation – have agreed to develop a cooperative effort under this umbrella.

The greatest revolution in ideas since Copernicus

According to Gudmund Hernes, we are in the middle of a revolution. Humanity is revising the way it thinks about itself and its relationship with the planet Earth. Not since Copernicus and his once heretical theory that the Earth revolves around the Sun has there been a comparable shift in thinking.

“In the past we thought that the world was near infinite and that the Earth was invincible. We could do what we liked with it. Now I am seeing an ever greater awareness of the fact that the world is fragile and that we are in danger of causing irreparable damage”.

Gudmund Hernes, researcher, professor of sociology and former minister in several Norwegian governments, has explored this topic through the eyes of the social scientist in in the book “Hot Topic – Cold Comfort, Climate Change and Attitude Change” published under the TRI umbrella. Professor Hernes focused on setting out assertions and theses as a basis for debate – and in time political action.

“It is important for me to describe how humans respond to the impact of their own interactions with nature. By this I mean that we do things to nature, and when we are faced with the repercussions of our actions, how do we react? In order to understand this we need to get the social scientists involved. Today we have a wealth of knowledge provided by meteorologists, climate scientists and oceanographers. But this is not enough. As experience has shown, knowledge in itself is never a sufficient basis for action”, says Hernes.

Several pivotal events

The aim of his report was therefore to mobilise the social science disciplines. Only when we understand how and why we have reacted so far can we take effective action. In preparing the report, he has observed the world as it has appeared since the Second World War, drawing on findings from his earlier research as well as from his own perceptions and experiences.

The conclusion he has reached is that several pivotal events together have prompted the majority of us to see the world as small and vulnerable. The bombing of Hiroshima on Monday 6 August 1945 marks the beginning of the ecological revolution.

“That event ushered in a long period that was dominated by the arms race, nuclear proliferation, and the threat of radioactive fallout – setting in motion a change in people’s attitudes. The next event I mention is the publication of Rachel Carson’s book Silent Spring, which documented the devastating effects of the synthetic pesticide DDT and led to the establishment of the first environmental protection agencies. Later came Agent Orange. That was when we began to realise that we could be destroying the world’s ecosystems”.

Gudmund Hernes
Photo: NordForsk/Terje Heiestad

Ph.D., Johns Hopkins University in Sociology, 1971.

Minister of Education and Research, later
Health and Social Affairs, 1990-1997.

Researcher at Fafo, an independent, multidisciplinary research
foundation and Professor at the Norwegian School of Business BI

The bombing of Hiroshima marks the beginning of the ecological revolution, according to Gudmund Hernes. The Atomic Bomb Dome, the ruins of the former Hiroshima Prefecture Industrial Promotion Hall which was destroyed by the first atomic bomb ever to be used in the history of humankind on August 6, 1945.
Photo: Jules Kitano/iStockphoto

“On Christmas Eve 1968, astronauts on board the Apollo 8 were the first to succeed in photographing the whole of the planet Earth. The photograph, called The Blue Planet, was considered one of the most important of the last century. It showed with dazzling clarity both how beautiful and how small our planet is”.

“Some of the events I have described happened suddenly, while others took place gradually over time. What they have in common is that they have been perceived as so dramatic that we have been willing to abandon our old ways of thinking as a result of them. And that is not something that happens easily!”

It is not until we are confronted with something that comes as a shock that we are prepared to change our opinions – and even then not until our friends and those around us have also done so.

In the midst of a revolution

According to Gudmund Hernes, the current ecological revolution represents an overwhelming shift in mindset, and is the most important shift in human thought since Copernicus. The reason that we do not experience it as dramatic today is that we are ourselves a part of it – and are right in the middle of it. It is all happening gradually. Similarly it took people several centuries to realise the true nature of the solar system.

The book “Hot topic – Cold Comfort” by Gudmund Hernes was published under the TRI umbrella in 2012. The book has been translated to Chinese.

“There are many reasons why this type of realisation is so deeply buried within us, and why it takes so long for people to change their long-held beliefs. Moreover, fully addressing the fact that humans are changing the Earth and the climate will require action and incur costs – for us as individuals, for trade and industry, for politicians, for society as a whole. Where should we store CO_2, for example? Who should pay to save the rainforest? We need decisions that involve investments. This creates political conflicts, and the decisions are delayed. But the longer we postpone implementing the necessary measures, the greater the changes we will need to make – and the greater the costs will be”, states Professor Hernes.

Appendix 1

Management Board of the Top-level Research Initiative for climate, energy and the environment

This overview lists all members of the Management Board from the programme beginning until 2015, but does not specify each member's period. The members' job title and employer at the time of their appointment to the board is included.

Denmark

Director **Nicolai Zarganis**, Danish Energy Agency

Head of Division for Research Infrastructure **Peter Sloth**, Danish Agency for Science, Technology and Innovation

Head of Division **Gitte Agerhus**, Danish Agency for Science, Technology and Innovation

Project Development Manager **Martin Wittrup Hansen**, Solum A/S

Finland

Director **Riitta Mustonen**, Academy of Finland

Director **Arja Kallio**, Academy of Finland

Director **Reijo Munther**, Tekes

Chief Technology **Advisor Juha Vaajoensuu**, Tekes

Chief Technology Officer **Petra Lundström**, Fortum

Head of Corporate R&D **Jussi Palola**, Helsingin Energia

Iceland

Professor **Gudrún Nordal**, University of Iceland

General Director **Hallgrímur Jónasson**, The Icelandic Centre for Research RANNÍS

Director **Bryndís Skúladóttir**, SI - the Federation of Icelandic Industries

Norway

International Director **Kari Kveseth**,
The Research Council of Norway

Director **Kirsten Broch Mathisen**,
The Research Council of Norway

Executive Director **Fridtjof Fossum Unander**,
The Research Council of Norway

Climate Director **Nils A. Røkke,** SINTEF

Senior Adviser **Cathinka Holtermann**,
The Research Council of Norway

Sweden

Director General **Rolf Annerber**g (Chair), Formas

Director General **Lena Gustafsson**, VINNOVA

Director **Lars Wärngård**, VINNOVA

Chief Strategy Officer **Jonas Brändström**, VINNOVA

Director General **Tomas Kåberger**, Swedish Energy Agency

Director General **Andres Muld**, Swedish Energy Agency

Director General **Erik Brandsma**, Swedish Energy Agency

Observers:

Faroe Islands

Director **Annika Sølvará**,
The Faroese Research Council

Greenland

Director **Klaus Nygaard**,
Greenland Institute of Natural Resources

Åland

Principal **Agneta Eriksson-Granskog**,
Åland University of Applied Sciences

Nordic Council of Ministers

Head of Department **Gard Titlestad**

Acting Head of Department **Fredrik Melander**

Senior Advisor **Daniel Holmberg**

Nordic Committee of Senior Officials for Education & Research (EK-U)

For the Icelandic Presidency 2009:
Eiríkur Smári Sigurðarson

For the Danish Presidency 2010
Special Adviser **Solveig Boesen**,
Ministry of Science, Technology and Innovation

For the Finnish Presidency 2011
Counsellor of Education **Annu Jylhä-Pyykönen**,
Ministry of Education and Culture

For the Norwegian Presidency 2012:
Assistant Director General **Pål Sørgaard**,
Ministry of Education and Research

For the Swedish Presidency 2013:
Desk Officer **Eva Stensköld**,
Ministry of Education and Research

For the Icelandic Presidency 2014:
Adviser **Una Strand Viðarsdóttir**,
Ministry of Education, Science and Culture

NordForsk

Director **Lisa Hakamies Blomqvist**
Director **Gunnel Gustafsson**

Nordic Innovation

Managing Director **Ivar H. Kristensen**
Acting Managing Director **Kari Winquist**
Managing Director **Roger Moe Bjørgan**

Nordic Energy Research

Director **Birte Holst Jørgensen**
Executive Director **Anne Cathrine Gjærde**
Executive Director **Hans Jørgen Koch**

Appendix 2
Editor's note

The Top-level Research Initiative (TRI) has been a large-scale initiative encompassing a great number of research and innovation projects and activities. The thematic focus has spanned a wide range – from analysing what is happening to the climate in the Arctic region, along with the resulting shrinkage of land ice, to measures to mitigate climate change in nature and society, to how new forms of energy and sustainable solutions in various areas can promote a more environmentally and climate-friendly Nordic region.

This book describes the main focus areas, key projects and important results. There are many additional TRI activities that we were unable to include within the framework of this publication.

The TRI was originally scheduled to conclude in 2014, but a number of its activities are extending over a longer period of time, some up until 2017. In addition, new topics and projects have emerged in the wake of the TRI.

Initiatives in areas such as green growth, the bioeconomy and the Arctic are continuing to address important research topics as well as new questions identified in the TRI projects. It will take many years before we truly know the final results of the initiative, as long-term perspectives are an intrinsic part of the research process. Many of the TRI's activities are based on national initiatives, and Nordic added value will have an impact on the national, Nordic and international levels in the future.

We would like to extend our thanks to everyone who has participated in the TRI, as well as those who have contributed time and knowledge to help make this book a reality.

Oslo, September 2015
Anne Riiser, Head of Communications, NordForsk

“I was very impressed by several parts of the programme. The engagement and the training of junior scientists has worked very well in all Nordic Centres of Excellence. I was also very impressed by the profiling of the projects at the global level. The centres have really made their mark and shown that the Nordic area can punch above its weight. Another thing was that the Nordic networking was extremely dynamic across all the three centres, and the networks that have resulted are very powerful.”

Mark Dickey-Collas
Ecosystem Approach Coordinator at the International Council for the Exploration of the Sea (ICES) and Chair of the Scientific Advisory Board of the programme “Effect studies and adaptation to climate change”

The Top-level Research Initiative

A major Nordic venture for climate, energy and the environment