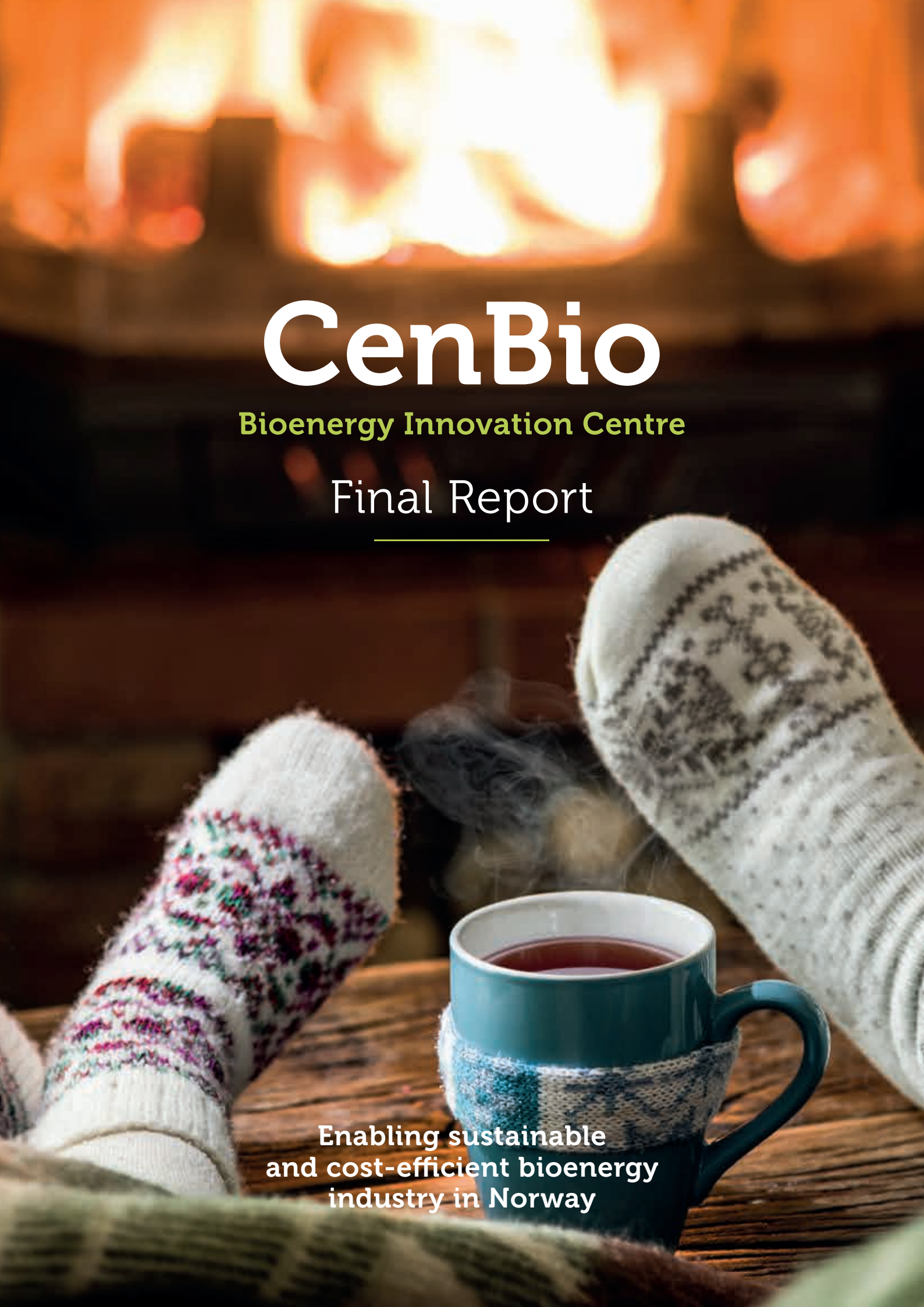

CenBio

Bioenergy Innovation Centre

Final Report

Enabling sustainable
and cost-efficient bioenergy
industry in Norway

Long live hygge

What else summarises the Norwegian way of life better than 'hygge'?

The word stands for an essential aspect of Scandinavian culture that we especially cherish in Norway. Laying on a cosy sofa in front of a wood-fuelled fire on a cold winter's day is about as Norwegian as it gets. This concept of 'hygge' is said to make homes nicer and people happier, and the burning of wood is a major part of it.

None of that would be possible without our partner Norges Skogeierforbund, which represents about 36,000 family forest owners. Throughout the past 8 years, the Bioenergy Innovation Centre (CenBio) brought them expertise from our top researchers to improve forestry logistics and forest sustainability.

Further along the chain, we worked closely with our two wood stove partners Norsk Kleber and Jøtul. The goal was two-fold: To help them to reduce particulate emissions from stoves, and contribute to a harmonised European test standard reflecting their high performance.

The results are highly valuable to the user partners

CenBio also focused on two more bioenergy value chains: district heating and biogas. The value-chain approach turned out to be a successful collaboration catalyst, drawing together knowledge and data from all R&D activities and all project partners. The results are highly valuable to the user partners.

Hosted by NMBU and led by SINTEF in a successful collaboration, the FME CenBio launched with 19 user partners and 7 R&D partners in 2009. Partly financed by the Research Council of Norway, CenBio created considerable value for industry thanks to the focus on stationary bioenergy and the main goal to enable sustainable and cost-efficient bioenergy.

We strongly acknowledge the very important educational pillar of CenBio. We thank the students and their supervisors who took part. The backbone of this research-based education is top-class international scientific co-operation.

Our hope is that you will find our final report inspiring. You are welcome to contact our researchers and user partners for additional information.

Marie Bysveen

Centre Coordinator
SINTEF Energi AS

Coordinating Institution

(Photo: SINTEF/Gry Karin Stimo)

Odd Jarle Skjelhaugen

Deputy Centre Coordinator
NMBU - Norges miljø- og biovitenskapelige universitet

Host Institution

(Photo: Erling Fløistad)

CenBio

Bioenergy Innovation Centre

Enabling sustainable and cost-efficient bioenergy industry in Norway

Final Report

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Cover: Shutterstock/Fagtrykk/Astrid B. Lundquist

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Summary

Together with key bioenergy user partners, CenBio research laid the foundations for a modern way of utilising biomass that many others will build on for years to come.

CenBio initiated two nation-wide movements: The coming together of industry from across the various biomass and waste-based energy value chains and an increased cooperation between the principal R&D sites at Ås and Trondheim.

The number of bioenergy projects has increased significantly, which illustrates the closer relationship between R&D and industry. At the same time, new actors from other sectors are now showing interest and entering the biomass and bioenergy markets. Furthermore, emerging industrial initiatives are expected to have an impact over both the short and long term, including biorefineries, liquid biofuel and biocarbon projects.

With innovation in the name, and "enabling sustainable and cost-efficient bioenergy industry in Norway" as a slogan, the

CenBio Centre Deputy Coordinator Odd Jarle Skjelhaugen in the Biogas Lab at Ås Campus.
Photo: Erling Fløistad.

need for CenBio to form close collaborations between industry and research partners was extremely important.

Benefits for bioenergy technology

Industry
New technologies and operating procedures for district heating plants have led to lower particulate matter and NOx emissions, higher energy efficiency and lower heat production costs. We also see new collaborative actions between actors in the sector.

New technology and operating procedures for biogas plants have led to higher biogas yields and new feedstocks like lignocellulosic biomass. As the cost of biogas production has decreased, biogas production in Norway has increased.

New woodstove technologies and designs have led to higher energy efficiency and lower particulate matter emissions from residential wood stoves, a must to avoid harmful air pollution in towns on cold winter days.

Science
Scientific documentation was a prerequisite for our industry partners to take the new knowledge into use. During the Centre lifetime, the researchers produced many peer-reviewed publications and conference presentations, some of them co-authored with industry and internationally renowned organisations. The scientific documentation proved decisive in the debate on bioenergy value chains and sustainability.

Value chains
Halfway through the Centre, we decided to conduct a lifecycle analysis of three distinct stationary bioenergy value chains: District heating, wood stoves and biogas. This successful effort turned into a collaboration catalyst, through the need for knowledge and data from all work packages.

Knowledge platform
Bringing together researchers from different disciplines along the bioenergy value chains made the Centre an attractive knowledge platform, resulting in many spinoff-projects and a new FME within biofuels. Thanks to infrastructure support from the Research Council of Norway, bioenergy labs of high quality are now in operation, which are an important asset for the future research.

Benefits for many

The knowledge exchange between industry and R&D through activities at partner plants, technical workshops and dissemination of research was an important benefit of CenBio.

Common bioenergy courses between NMBU and NTNU along with high numbers of PhD candidates and Master students, and the high number of spin-off research projects helped to ensure a bright future for bioenergy research and development in Norway.

Scientific output was high with 256 peer-reviewed publications and more than 250 presentations given at many international conferences. These included a major presence at the European Biomass Conference and Exhibition (EUBCE) in 2016, which helped to put CenBio on the global bioenergy map.

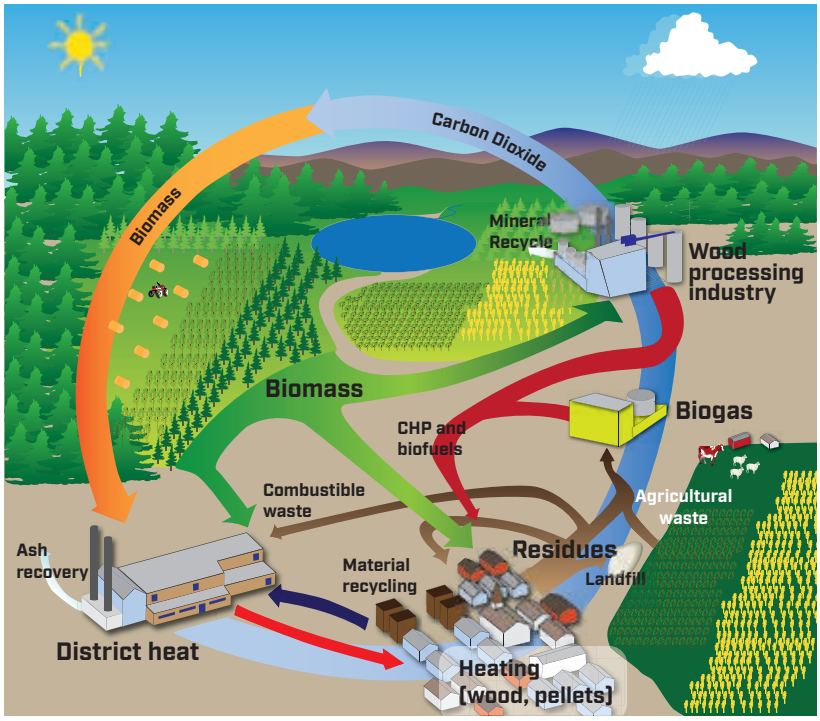
46 Master students, 33 PhD candidates, 7 PostDocs and 20 completed innovations were associated with CenBio. Technical contributions on specific elements in the bioenergy value chains included an improved mapping of forest resources and optimisation of logistics, waste characterisation and improved ash knowledge, emissions mapping in combined heat and power (CHP) plants, new feedstocks and improved biogas production, and cleaner and more efficient wood stoves.

More than 200 international collaborations from 33 countries resulted in peer-reviewed publications within CenBio. The scientific and industrial bioenergy communities benefited from CenBio collaboration and as a result, CenBio met the targets set by both the Research Council of Norway and the user partners.

Vision and Goal

To enable sustainable and cost-efficient bioenergy industry in Norway

CenBio has addressed the entire value chains of virgin biomass and waste fractions, including their production, harvesting and transportation, the conversion to heat and power, and the upgrade of residues (ash) to valuable products. CenBio researchers have contributed to the development of more effective, environmentally sound ways of utilizing more biomass and waste for energy purposes. Educating and training the next generation of bioenergy researchers and close collaboration with industry actors are essential to attain these ambitious goals.



As a result, consumers and society will be supplied with more renewable and low-carbon energy.

Research partners

Norwegian University of Life Sciences · SINTEF · NTNU · NIBIO · VATTENFALL

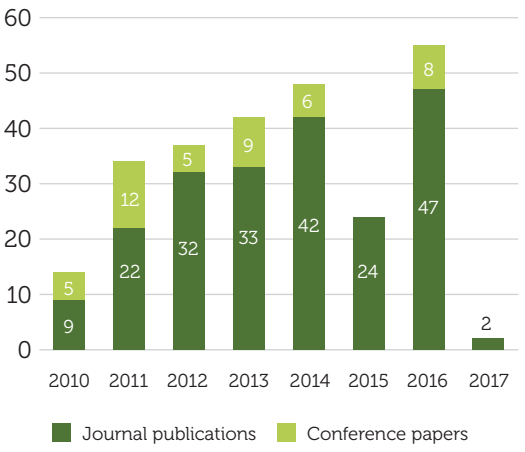
User partners

Akershus Energi · Statkraft · Hafslund · Norges Skogeierforbund · EGE Energigjenvinningsetaten

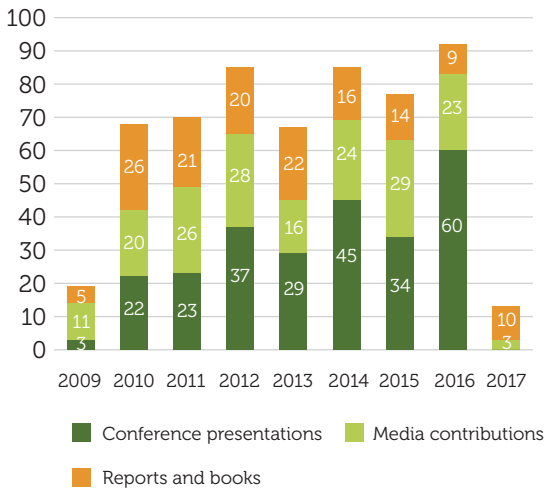
VATTENFALL · ENERGOS · CAMBI - recycling energy · JØTUL · NORSK KLEBER 1893

Eight years in numbers

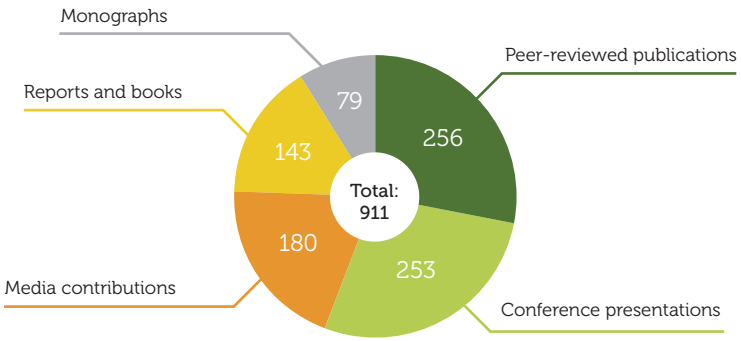
More than 250 peer-reviewed publications



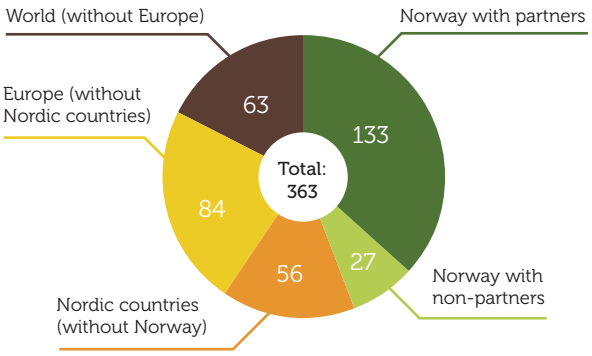
A constant effort to present our work



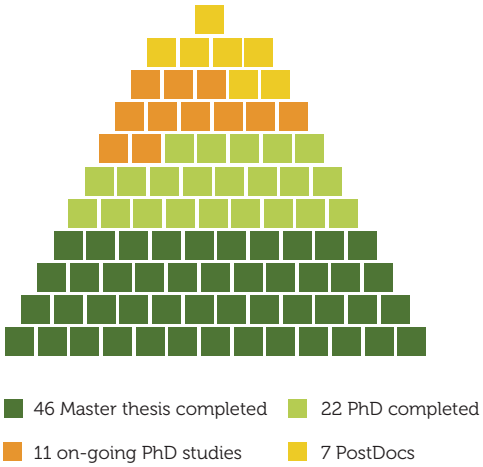
Communicating our results to the rest of the world



Placing CenBio on the world map through national and international collaborations leading to peer-reviewed publications



Training the next generation of bioenergy researchers



Other CenBio highlights

46	33	7	20
Master Thesis	PhD candidates	Post-Docs	Completed innovations

From plants to biogas

The world is crying out for more fuel. CenBio investigated if biogas holds the answer to a sustainably-fuelled future.

Biogas is produced by the degradation and fermentation of organic matter in the absence of oxygen. The process known as anaerobic digestion produces methane and carbon dioxide, which makes up the biogas. The biogas is being used for heating, electricity generation and as a substitute for fossil fuels in transportation. The rest product, a liquid called the digestate, is a valuable organic fertilizer that replaces energy-intensive mineral fertilisers and further mitigates greenhouse gas emissions.

The production of biogas is the most direct route from biomass to fuel

Biogas production has grown rapidly over the years in Norway and many other countries in Europe, mainly due to increasing global concerns about CO_2 emissions from the energy sector and enhancement of energy supply security.

"The production of biogas is the most direct route from biomass to fuel. We decided to study cellulose as a potential feedstock raw material because of its high energy content, and because this is the biomass that nature produces most of," says Research Director Tormod Briseid from NIBIO.

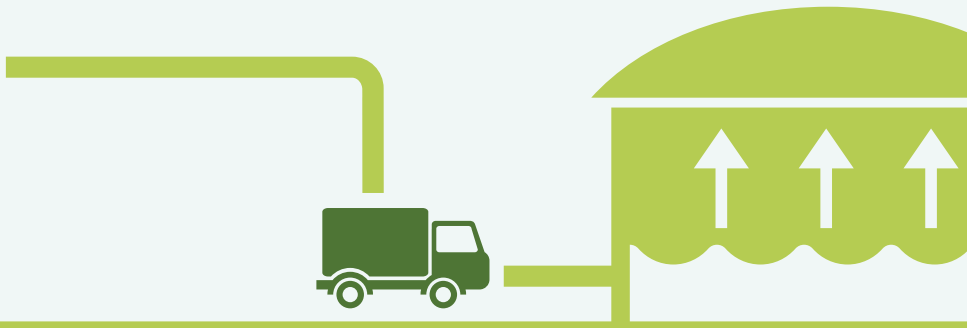
An undoubted highlight for CenBio was the opening of a new biogas laboratory at Ås by the Minister of Agriculture in

Substrates

Substrates: fish waste, food waste, sewage sludge, cellulose-rich material (birchwood, straw)

Biogas production

Substrates are processed through anaerobic digestion



Biogas valu

2011, which enabled much of the following research.

Inside the reactor

In the biogas process many different microorganisms work together and form a complicated 'degradation web'. Some micro-organisms attack the large molecules such as proteins, polysaccharides like cellulose and starch, fats and others. They produce acetate, formate and many other monomers which in turn are further degraded to a mixture of methane and CO_2 (biogas) by the different methane-forming micro-organisms.

In CenBio molecular biology has been used and further developed to study the microbial community structure and the correlation between population dynamics and process performance. The results indicate a correlation between operational parameters like the digester configuration, feedstock, process temperature and the microbial community structure. A further step is to use this information to obtain robust and effective biogas processes.

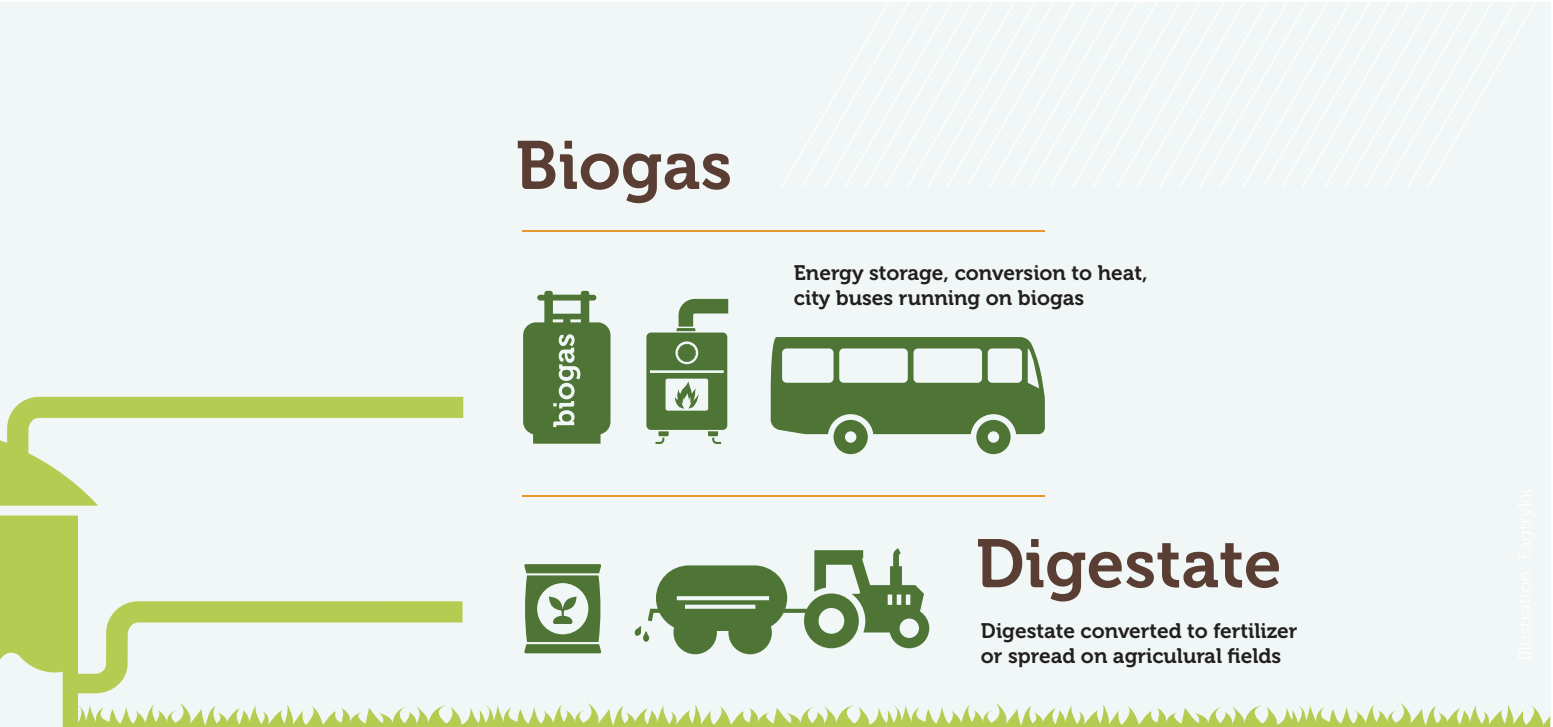
Pre-treatment breakthroughs with Cambi

CenBio's industrial biogas partner was the Norwegian company Cambi AS, which supplies biogas plants worldwide. The company's technology for steam-based pre-treatments of the feedstock was highly relevant to our research activity. Cambi was invited to join CenBio to bring this valuable industrial knowledge and their own questions to the table.

> Through CenBio we have been able to expand our activities to look at a broader range of substrates for energy production

"The long-term FME funding commitment allowed everyone to plan sensibly and make investments that would give benefits for years to come" says Cambi's research and development director Pål Jahre Nilsen. "Through CenBio we have been able to expand our activities to look at a broader range of substrates for energy production. The shift in focus onto life cycle analysis and the whole biogas value chain was an important move for the Centre, which allowed us to put some of these processes in the proper context."

In 2012, Cambi won the Bioenergy Innovation Award for their innovative biogas production process for biomass from waste and sewage. The new facilities at Ås enabled a much deeper study of the preparation process.



ue chain

Lab-scale steam explosion unit for processing woody biomass prior to feeding into a biogas reactor. Featuring NMBU professor Svein Jarle Horn (right) and NMBU research scientist Bjørge Westereng (left).
Photo: Odd Jarle Skjelhaugen.

The method involves heating raw material with pressurised steam up to a temperature between 130 and 210°C, and then release the pressure rapidly. This steam 'explosion' opens up the fibres in the material, allowing bacteria and enzymes to more easily do their degrading job.

"It's actually a simple idea. Think of how much easier a raw vegetable is to eat once it has been cooked. The fact that decomposition of organic matter happens much more quickly after pre-treatment is essentially the same concept," explains Briseid.

New feedstocks

Until recently, most biogas plants used food waste, sewage sludge and livestock manure as feedstock. Dedicated teams in CenBio investigated the potential for generating biogas from cellulose-rich biomass such as birch, willow and straw. In this way, we could increase the feedstock base, and because of that, increase the volume of biogas produced in Norway.

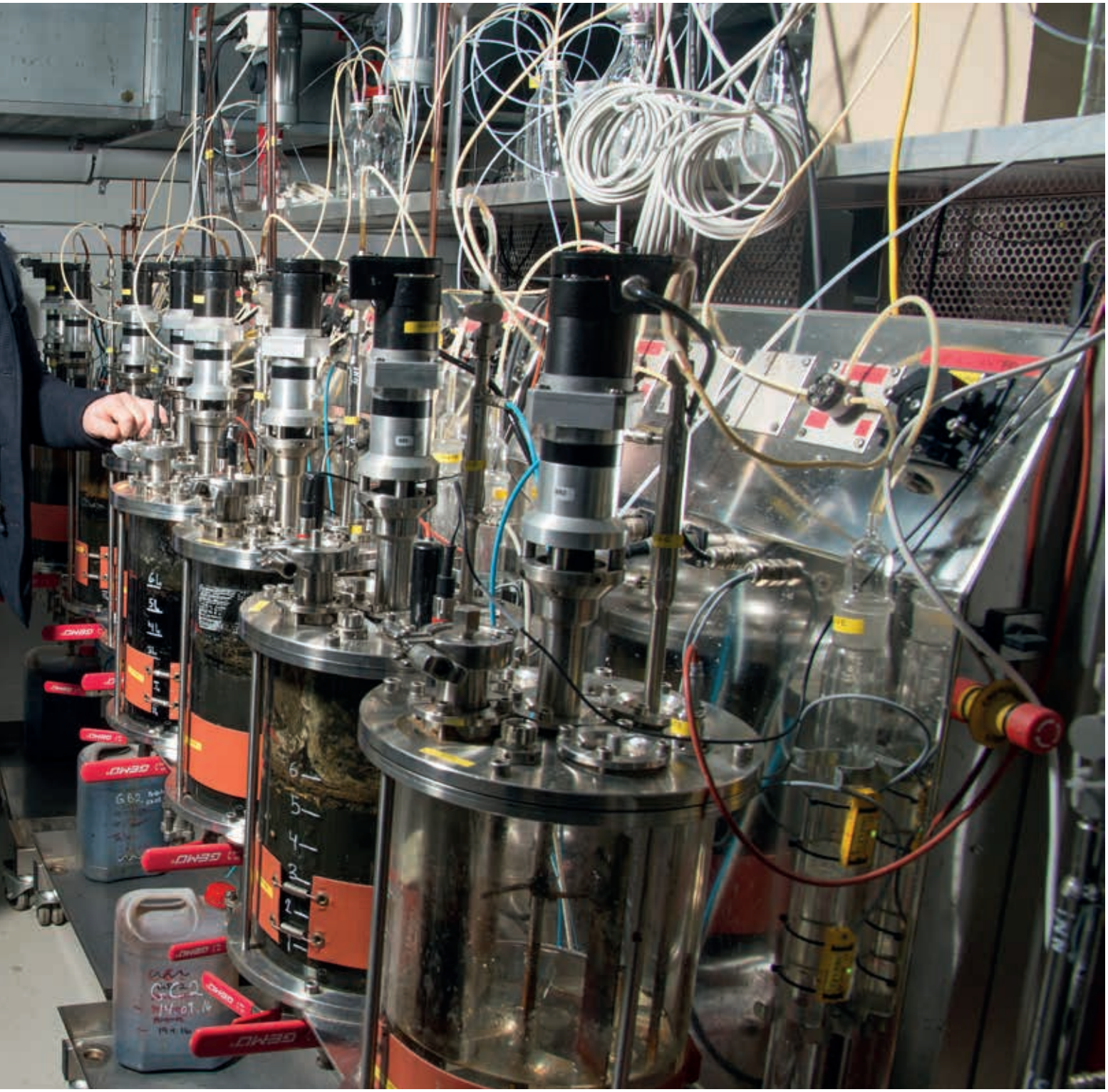
The results were impressive. By using the steam pre-treatment at about 210°C for ten minutes, the biogas yield from milled birch doubled, compared to the yield from non pre-treated milled birch. The biogas yield results are shown in the figure on page 14.

Maximum methane yield from cellulose is in the range of 350 – 400 mL per gram cellulose. Steam-exploded birch yielded the same. This demonstrates the value of including steam explosion in the process when introducing cellulosic feedstocks.

This knowledge opens up possibilities for biogas production from new biomass blends such as nitrogen-rich fish farming sludge and carbon-rich woody biomass like birch.

This knowledge opens up possibilities for biogas production from new biomass blends

Another option could be to blend steam-exploded woody biomass and municipal food waste to improve the carbon/nitrogen balance in the reactor and thereby increase the gas production and the microbial stability.



NMBU senior research scientist Roar Linjordet in the Biogas Lab at Ås Campus.
Photo: Erlind Fløistad.

More than just biogas

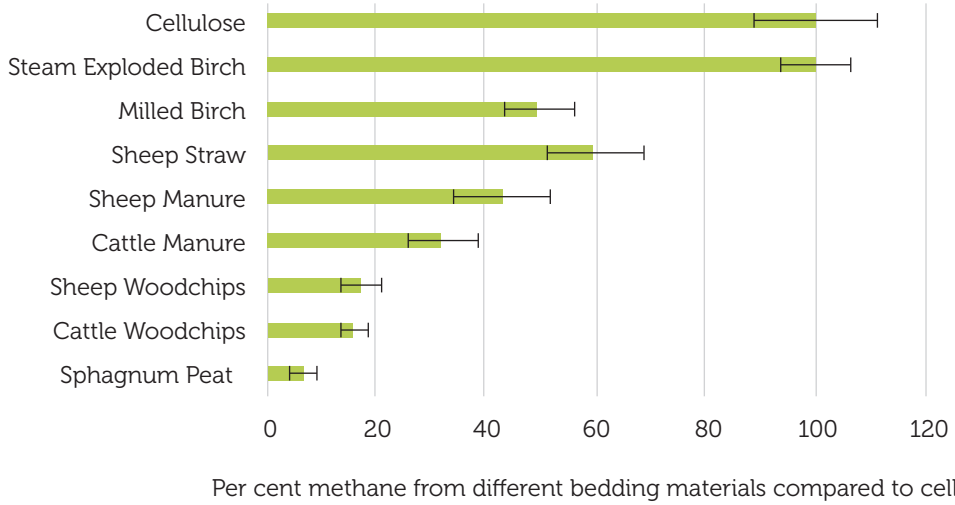
It will not be possible to convert all types of raw material into biogas. There will always be some organic rest products, typically containing phosphorous, nitrogen and potassium. These nutrients can be mixed with water and used as fertiliser, which turned out to be of significant interest to the Centre's user partners.

"Efficient raw material harvesting and distribution of the bio-fertiliser by-product is important in cellulose-based production of biogas. That's why it was useful for us that CenBio investigated the whole value chain," says Nilsen.

Co-funded by CenBio, Eva Brod successfully defended

Birch, a potent biogas feedstock.

Photo: Shutterstock.



Potential methane production from different feedstocks. Cellulose and steam-exploded birch have the highest possible potential. Figure: Roar Linjordet, 'Biogas potential of deep litter bedding materials', 24th NJF Congress Nordic Association of Agricultural Scientists Uppsala, Sweden, June 14–16, 2011.

her PhD thesis on the recycling potential of phosphorus in bio-resources both from land- and marine-based sectors in Norway. In cooperation with the industrial ecology programme at NTNU, her study showed that there is large potential for increased phosphorus recycling in Norway, and a potential for major reductions in the use of mineral phosphorus as fertiliser.

Understanding the environmental sustainability of biogas

To help industry and policy-makers to understand biogas as a potential fuel of the future, CenBio took a value chain approach, integrating a wide range of expertise and knowledge. The climate impact assessment included emissions of ozone precursors and aerosols, which are frequently overlooked in Life Cycle Assessments, and the application of a suite of different emission metrics based on either the global warming potential or the global temperature change potential. The disposal of the digestate was identified as the main hotspot, mainly due to methane losses from the open storage.

NTNU professor Francesco Cherubini led the value chain activity. "Electricity from biogas can save between 76 and 115 g CO_2 –eq. per MJ when compared to electricity from natural gas. Other environmental impact categories should be reflected in an assessment, such as eutrophication, acidification, toxicity, and primary energy consumptions. All these factors must be considered in the quest for sustainable energy production from biogas," he says.

To be more realistic about the biogas value chain in a Norwegian context, the team worked in close collaboration with the Lindum plant, located in Drammen and which uses Cambi technology.

Momentum of biogas in Norway

Germany, Denmark and the Netherlands are the main biogas players in Europe. However, the number of biogas plants in Norway has increased in recent years. In 2014, the Norwegian government approved a national biogas strategy to stimulate the production of biogas from different substrates. In 2015, 45 plants produced 360 GWh of biogas. 60% of the plants processed sewage sludge, the remaining plants processed food waste and agricultural waste. 60% of the biogas produced was used for vehicle fuel, 30% for heat and 10% for electricity.

Phosphorus-rich waste materials used as fertilizer in a pot experiment.
Photo: Eva Brod

Burning wood: from forest to stove

Thanks to the Scandinavian love of *hygge*, small-scale wood combustion in wood stoves accounts for almost half of the bioenergy use in Norway. CenBio research aimed to increase efficiencies and decrease emissions.

Many aspects affect the efficiencies and economics of burning wood, from the environmental impact on the forest to the technology we use to burn it. Together with industry, CenBio took a holistic view of the wood burning chain from forest to stove, in order to identify areas where it is possible to increase efficiencies, reduce emissions, and improve use of resources.

Although improvements in wood stove technology reduce harmful emissions, such technology improvements have a cost.

As part of the value chain analysis, an integrated analysis of environmental and economic aspects of two different wood stove technologies was performed. The environmental analysis looked at old and new wood stoves, the latter with staged air combustion technology to reduce particle emissions. From an economic perspective, costs of different wood stove technologies and operational modes were

1.2 million tons

wood burnt for heating Norwegian houses in 2015

(source: SSB)

compared. Costs were analysed both on a non-profit basis and with margins added, helping to reveal potential trade-offs between environmental and economic interests.

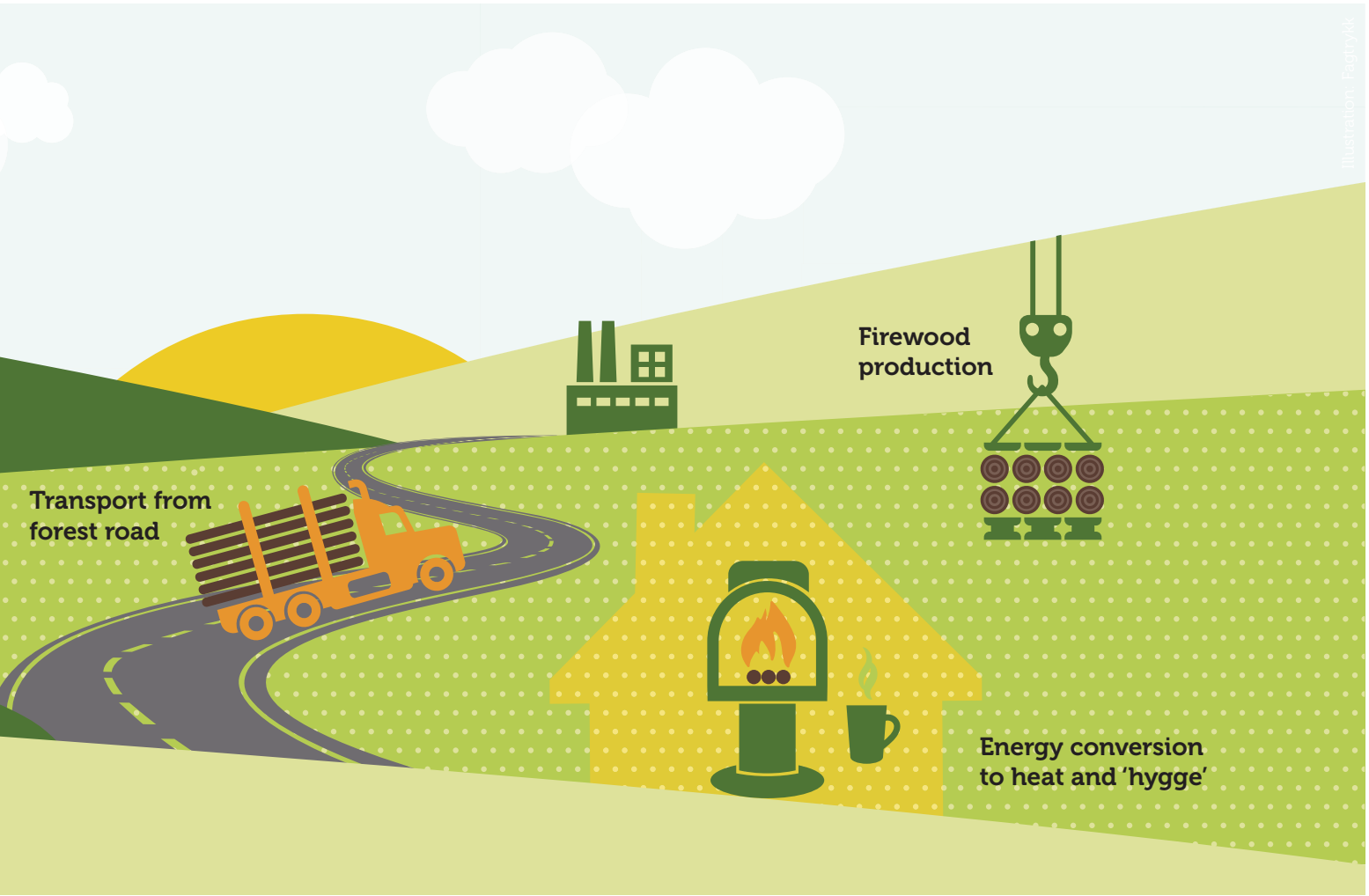
A clear trade-off

Results showed that the switch from old wood stove technology to new technology with staged air combustion leads to a decrease in all emissions and impact categories. However, we see that the effect of the stove load is even more important for many of the impacts and emissions. Climate change impacts due to emissions can be reduced by more than 80% and particulate matter by more than 90%, going from the most polluting technology to the cleanest. Combustion in the wood stove is the main contributor to all impacts and emissions except ozone depletion and freshwater eutrophication, where wood transportation dominates.

The results from the economic analysis show that the cost reduction from the most expensive to the cheapest technology is approximately 10%. The largest costs arise at the end of the value chain, where operational expenditures for transportation and firewood production and capital expenditures for the wood stove make up approximately 75% of the cost. Adding margins to the levelized cost of energy, we see that even a moderate margin of 10% affects the cost as much as switching from the cheapest to the most expensive technology.

Climate change impacts due to emissions can be reduced by more than 80% and particulate matter by more than 90%

"Comparing the results from the environmental and economic analysis, we see that there is a clear trade-off in terms of environmental impacts and costs," explains Research Scientist Carine Lausselet from NTNU. "The cleanest technology is the most expensive and the most polluting is the cheapest. However, relatively speaking, the emission reductions are substantially higher than the cost increase. For both environmental impacts and costs, the main hotspots in the value chain are



transport and combustion in the wood stove."

Morten Seljeskog in the NRK TV programme Forbruker-inspektørene on 15 January 2014.
Photo: Facsimile NRK.

Do you know how to light a stove correctly?

Morten Seljeskog, Research Scientist at SINTEF, was invited by the Norwegian national broadcaster NRK to talk about how to use wood stoves.

"Incorrect use of a stove, especially when lighting it, creates inefficiencies at the very end of the chain so it is important to spread such knowledge. For many stoves, there is great potential for reducing environmental impacts by changing the way people interact with them, and along with improved design this requires improved education," Seljeskog says.

For many stoves, there is great potential for reducing environmental impacts by changing the way people interact with them

Such a wood stove can store heat. Throughout the collaboration with CenBio, Norsk Kleber stoves achieved cleaner combustion.
Photo: Norsk Kleber.

The Jøtul factory in Fredrikstad.
Photo: Morten Seljeskog.

Green heat from soapstone

From Brussels came a new standard that could have cast a dark cloud over the future of Norwegian stove manufacturer Norsk Kleber. However, the company kept up its spirits by tackling the problem head on, and managed to reduce its stoves' particulate emissions.

Norsk Kleber and its 18 employees, based in the little town of Otta, produces stoves and fireplaces made of massive soapstone. Unlike most wood-burning stoves, these stoves store heat, and such stoves are usually large and heavy. The new European Union regulation would only let heavy models through the eye of the needle, so Norsk Kleber, with its relatively light-weight models, needed to find another way. The solution was to redesign the stoves so that they met the requirements of the Norwegian standard for wood-fired stoves by fitting them with afterburners. These feed preheated secondary air into the flue gas through holes in the burn-plate, thus enabling the uncombusted gases to burn up completely.

The afterburners for the Otta stoves were designed by the CenBio programme as a cooperative project involving the company itself and SINTEF's Edvard Karlsvik, the 'grand old man' of Norwegian wood-stove research and CenBio Innovation Award winner in 2011. According to Norsk Kleber's managing director Torbjørn Randen at the time, the result was a 'win-win' situation:

"Particle emissions were reduced while the combustion efficiency of the stoves increased. For a small company like ours, it is vitally important to be able to collaborate with research groups," he says.

Wood stove standardisation

A range of national standards, test methods and labels have emerged to compensate for the currently outdated standard for residential solid fuel burning appliances, meaning costly, confusing and time-consuming approval processes for the manufacturers. There is no harmonised particle emission measuring method for fireplaces and wood stoves in Europe.

What interested CenBio's user partners Jøtul and Norsk Kleber the most, was the need for harmonised standards.

CenBio researchers played an active part in the work led by Central European Norms (CEN), one of three European standardisation organisations officially recognised by the EC and EFTA as being responsible for developing and defining voluntary standards at European level.

CenBio researchers helped to create a series of documents on residential solid fuel burning appliances, including general requirements and test methods, room heaters, inset appliances including open fires, cookers, independent boilers (nominal heat output up to 50 kW), slow heat release appliances, and appliances fired by wood pellets.

The current documents now include two modified versions of existing methods for measuring the total number of suspended particles, one with and one without using a dilution tunnel. The latter one is an altered version of the current Norwegian dilution tunnel test method NS 3058-59. SINTEF Energy Research, SP Fire Research, Standard Norway and the Norwegian Environment Agency all played a valuable part in the compilation of these standardisation documents.

NIBIO research scientist Aaron Smith on a field trip removing dirt and debris from a root system in order to estimate below-ground birch biomass.
Photo: Marketa Stenova.

A journey into the forest

As important as wood stoves are to the wood burning process, the journey begins back in the forest. CenBio examined how forest resources can be better managed to ease the successful transition to the bioeconomy.

"CenBio opened up the possibility for us to look at using the whole tree," explains Senior Advisor Simen Gjølsjø from NIBIO. "We showed our user partners how value could be gained across the forest from branches to roots and residue, not just from the tree trunks."

This work was essential for our partner Skogeierforbundet, the Norwegian Forest Owners' Federation, which represents about 35,000 forest owners in Norway. Research focused on the availability of biomass and estimation methods to help analyse the long-term production potential from Norwegian forests.

"Forest management is a complex task where conflicting interests often need to be handled," says Professor Tron Haakon Eid from NMBU, who led the work on assessing the biomass supply.

"There are 20,000 identified forest plots covering Norway that have been monitored every five years for the last 30 years. This gives us a very good dataset from which to examine changes in biomass availability."

Eid goes on to explain why the group chose to focus on cost. "It's expensive to get all this biomass from the forest to the road and onto its final destination. Not only is it expensive, but with the fjords and mountainous terrain that we have in Norway, the cost varies a lot too."

We showed our user partners how value could be gained across the forest from branches to roots and residue, not just from the tree trunks

Estimation of biomass

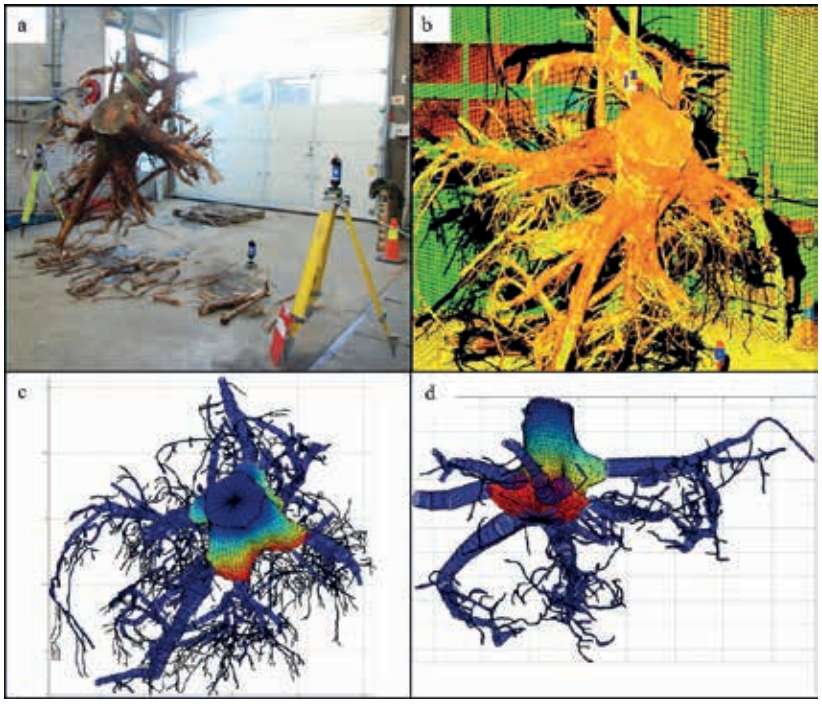
Funded by CenBio, NMBU PhD candidate Aaron Smith successfully defended his thesis on improving individual tree biomass estimation. As part of his substantial fieldwork, Smith studied tree root architecture of spruce and birch and developed belowground birch biomass functions. The derived data set for belowground birch biomass is the largest in Scandinavia and the developed functions are likely to be the best available for estimating national birch biomass stock and stock change in Norway.

"Very little had previously been done on assessing the biomass estimation of roots and branches. This innovative work has made a significant achievement facilitating accurate estimation of improvement to assess the biomass stock in Norway, both belowground and aboveground," says Eid.

Optimisation methods

Research into bio-economic optimisation methods handling links between forestry methods, economic behaviour, sustainability criteria and biomass supply in forest decision-support tools also took place, with the work of NMBU PhD candidate Paulo Borges being particularly important.

For certain Norwegian forested areas, law regulations do not allow large clear cuttings. One of Borges' studies focused on methods related to maximum opening areas in harvest operations, with the objective of developing methods minimising profitability losses because of such restrictions. Borges also studied the effects of different environmental restrictions on available timber and biomass quantities from the forests surrounding Oslo. Results show that the restrictions reduced profitability by up to 20%, although a supply of 20-30 GWh annual energy from harvest residues can still be provided from the municipal forest.



Root system images: (a) Root system at scanning; (b) Terrestrial Laser Scanning cloud data of a root system; (c) Top view of the cylinder fitting modelling; (d) Bottom view of the cylinder fitting modelling.

Photos: Aaron Smith.

Managing the forest ecosystem

CenBio researchers also played a part in projects examining the consequences of removing harvest residues (branches and tops) from the forest ecosystem. Field experiments took place in both the east and west of Norway, where vegetation and climate conditions differ greatly. Effects of both stem harvesting and whole tree harvesting on the soil quality and biodiversity of the surrounding vegetation were studied. The results of current experiments and field studies going back forty years were modelled along with literature review data of other studies to create a set of guidelines.

"It was not so easy as with the diversity of the Norwegian forest, one size does not fit all," says NIBIO senior research scientist Nicholas Clarke. We found a lot of variation in the results, which were very site specific. If you have a nutrient-rich site, you can remove residues with less short-term effects on the next

NIBIO senior advisor Simen Gjølsjø in front of Statkraft Varme's district heating plant at Ås Campus.

Photo: Erling Fløistad.

generation. Piling of residues has a short-term effect on the ground vegetation, although the potential long-term effects are more difficult to predict."

Tackling supply chain challenges

Forest biomass supply to heating plants is subject to diverse constraints in the supply chain, from harvest to transport logistics, and challenges related to storage and preserving or increasing biomass quality before it is used for bioenergy.

Moisture is one of the most important quality parameters. The standard method currently used for determining moisture content is oven-drying at 105°C until stable weight is reached. It takes at least 24 hours before the moisture content is determined, which is a disadvantage for buyers.

Nordic forestry research institutes of Sweden (Skogforsk), Norway (NIBIO) and Canada (FPInnovations) joined forces in a collaborative study aiming to test whether the Near InfraRed (NIR) Prediktor Spektron Biomass moisture meter had the necessary measurement accuracy for determining moisture content in forest biomass trading, with a particular emphasis on frozen material, a critical factor in Scandinavia.

"It is an instrument that can measure moisture content in near real-time using infrared light," says Senior Engineer Eirik Nordhagen from NIBIO. "Previously we had to wait up to 24 hours to find out the moisture content. We also want to measure moisture content when the chips go into the boiler. You can now take a sample and find out the moisture content immediately."

"Forestry companies in Norway wanted faster measurements, and I think this will be especially relevant for the larger heating plants. Now the instrument has been officially approved in Sweden for buying and selling of woodchips, it seems likely to be accepted in Norway too."

> Previously we had to wait up to 24 hours to find out the moisture content

Fruitful hunt for small trees

A PhD study financed by CenBio could help to reduce the costs of 'first thinning' of forests, which would be good news for forestry and the bioenergy industry.

Forest owners have always dreamt of being able to thin their trees at an early stage of growth, to enable the remaining stock to develop optimally and produce high-quality timber. However, in Norway, as in other countries, there has been a lack of customers for the small trees.

"But now, bioenergy could become a market for this assortment," says NIBIO research scientist Helmer Belbo who collaborated with Skogforsk, the Swedish forestry research institute.

If this turns out to be true, the result will mean a 'win-win' situation; improved growth conditions for timber production, and greater availability of energy-rich raw material for the bioenergy industry. However, one problem does remain; how can we make this small tree

NIR Prediktor Spektron measuring moisture content of wood chips in real time.
Photo: Eirik Nordhagen.

Studies of technology for extracting small trees formed the basis of a PhD study that could lower the cost of harvesting the first thinning in forests.

Photo: Helmer Belbo.

harvesting cost-effective? Belbo's PhD work, financed by CenBio and defended in 2011, focused on this exciting question.

"Sweden and Finland take out large amounts of small timber for energy production, but even there, subsidies are essential," says Belbo.

"In our practical studies, we identified relationships that are important for product yield, in terms of both tree-felling equipment and methods of employing such equipment. New equipment shows that manufacturers have begun to adopt our findings. But in my opinion, both the technology and the methods involved have not yet matured sufficiently. There is still more to be done, and we are working on some concrete ideas to further improve productivity."

New equipment shows that manufacturers have begun to adopt our findings

The question of sustainability

Driven by the increased market and environmental costs of fossil fuels, biomass for energy is projected to increase considerably in the near future. Biomass provides options for power system reserves and regulation, and may provide possibilities to achieve long-term negative CO_2 emissions through bio-CCS technologies.

The amount of wood biomass used to produce heat, power and liquid biofuels has increased during the last decade. In Norway, only about half of the annual forest growth is harvested, and only a minor fraction of the forest residues is utilized. In addition, the possibilities for increased forest growth through the intensification of forest management are considerable. This situation implies that the potential for increased use of wood biomass in the new bioeconomy is high.

"Sustainable bioenergy can be one of the cornerstones of renewable energy supply when moving to a low carbon society," says Professor Birger Solberg from NMBU.

Sustainable management is currently implemented on more than 85% of the Norwegian forests through certification systems. To achieve sustainable bioenergy, it is essential that the climate impacts of increased use of forest biomass for bioenergy are favourable. While the choice of the energy technologies matters, all main climate impacts must be considered including albedo and the international market effects of changing harvest in Norway.

Award-winning research

Research supported by the Centre received international recognition. Here is a selection of awards received during the life of CenBio.

Best Paper at FBC conference

Håkan Kassman of Vattenfall and Lars-Erik Åmand, Chalmers University of Technology, received the Best Paper Award at the 22nd Fluidized Bed Conversion (FBC) conference in Turku, Finland in 2015.

Kassman performed the experiments for 'Aspects on the flue gas chemistry of KCl, NO and CO during injection of ammonium sulphate – An experimental approach' while studying for an industrial PhD degree at Chalmers, but the financial support from CenBio gave him the opportunity to further evaluate the results and write the award-winning paper.

Laudise Medal to Anders Hammer Strømman

NTNU professor Anders Hammer Strømman and his group played a substantial role in CenBio, contributing to the Value Chain and life cycle analysis work. In 2011, he received the Laudise medal in Industrial Ecology. The Laudise Medal is awarded every second year by The International Society for Industrial Ecology (ISIE) to a researcher who has made an excellent contribution to research in industrial ecology in the early part of their career.

The award was handed out during the ISIE conference at UC Berkeley in 2011. The jury

Lars-Erik Åmand and Håkan Kassman receiving their Award.
Photo: Chalmers University.

NTNU professor Anders Hammer Strømman.
Photo: NTNU.

SINTEF research scientist Judit Sandquist operating a TGA (Thermogravimetric analyser) for assessment of thermal conversion behaviours of biomass and waste feedstocks under well-controlled conditions.
Photo: SINTEF/Geir Mogen.

emphasized that Strømman has given a substantial contribution to improve the methodology for life cycle analysis, and highlighted his work within environmental assessment of bioenergy and global production systems.

NMBU professor Birger Solberg.
Photo: Håkon Sparre

Strømman also contributed as an author to the third working group of the 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC).

Schlamadinger award from Climate Policy

NMBU professor Birger Solberg was the leader of the sustainability and market analysis activity. Solberg, Hanne Sjølie (NMBU) and Greg Latta (Oregon State University) were awarded the Schlamadinger prize for the best journal paper on climate change, forestry, land use and bioenergy by the Climate Policy journal in 2013.

Judges praised the paper 'Potential Impact of albedo incorporation in boreal forest sector climate change policy effectiveness' for demonstrating the significant adjustments needed for an improved forest management for climate change mitigation.

The dream fuel is already here

Not all types of biomass are equally easy to use as fuel in terms of combustion technology. Torrefaction offers a promising solution to this problem.

There are plenty of inexpensive fuels to be found in nature; some examples are branches and tree-tops (GROT in their Norwegian acronym), and straw. However, these types of raw materials are difficult to handle, and they can damage furnaces and reduce combustion efficiency.

"Torrefaction transforms logging residues and straw into a homogeneous fuel with high energy density," says SINTEF chief scientist Øyvind Skreiberg. Moreover, this fuel can be easily stored and transported, and just like coal, it can tolerate getting wet.

In the dry torrefaction process, the raw material is heated to 200-300°C, thus breaking down its fibrous structure. This makes the fuel easier to grind down to a powder and then moulded into pellets.

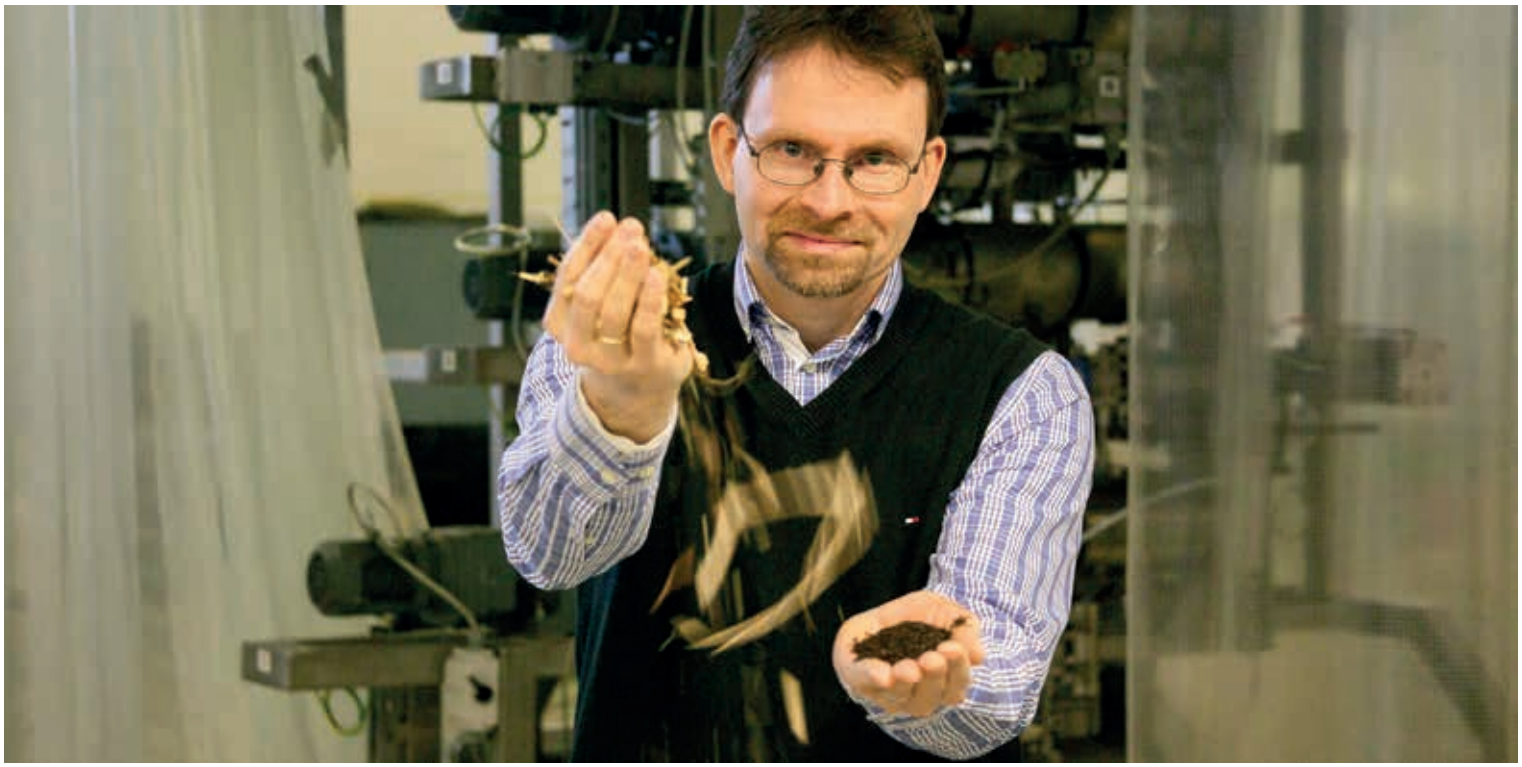
"Our hope is that torrefaction will make cheap and problematic biomass fuels easier to handle and enable improved combustion properties"

In CenBio, SINTEF used a specially constructed laboratory setup to study how different production conditions affect the quality of the end-product fuel. These combustion characteristics are checked in an instrumented pellet stove.

A common concern is that torrefaction will make the energy from such fuels too expensive, something that Skreiberg believes can be dealt with.

SINTEF chief scientist Øyvind Skreiberg.

Photo: SINTEF/Gry Karin Stimo.



"Our hope is that torrefaction will make cheap and problematic biomass fuels easier to handle and enable improved combustion properties. The low price of the raw material itself is precisely what can make this method competitive," he says.

Wet torrefaction

The success of the torrefaction technique led to a spin-off project. Initially led by CenBio, the KMB STOP (Stable Operating conditions in biomass combustion plants) was completed in 2013 and has since led to further spin-off activities.

A driving force in the project was the NTNU PhD study of Quang-Vu Bach, who focused on fuel property improvements during wet torrefaction (WT).

WT is a promising method for the pre-treatment of biomass for use as a fuel. The method involves the use of hot compressed water as reaction medium. Because of the water use, WT is highly suitable for low-cost biomass resources such as forest residues, agricultural waste, and aquatic energy crops, which normally have very high moisture content.

In his PhD thesis 'Wet torrefaction of biomass - Production and conversion of hydrochar' it was found that WT has positive effects on the fuel properties of biomass, and additionally the following benefits over dry torrefaction:

- The elimination of the pre-drying step as WT takes place in a hydrothermal medium.
- Easier pelletisation because the wet torrefied biomass does not require the addition of water to improve the pelletability, i.e. the binding properties.
- The ability to dissolve some of the inorganic components produces a 'cleaner' solid fuel with respect to removal of some of the inorganic content; an advantage that is highly beneficial in combustion and gasification processes.

"Through the STOP project we studied the combustion efficiency and polluting emissions of raw and torrefied biomass in a pellet stove combustor for residential heating," explains Skreiberg.

"One important finding was that technology should be modified to perform optimally with a fuel torrefied at high temperatures. This is most critical for micro-scale installations such as pellet stove combustors. For larger scale plants like grate combustion plants, tweaking operating conditions will probably be sufficient."

Taking the next steps with torrefaction

Great progress was made with this research and torrefaction is still a hot topic internationally, but the issue now is putting the specific research into practice.

"Internationally there are some pilot- and demonstration torrefaction plants and a few pre-commercial plants, but no full-scale commercial producers of torrefied material and there has not yet developed an international market for this as a commodity. Norway could, and maybe should, be a part of this future. Pellets made from torrefied biomass could contribute to a larger national biomass resource base and improved operational performance and reduced emissions in bioenergy plants," says Skreiberg.

SINTEF research scientist Roger A. Khalil and the torrefaction experimental setup (next page).
Photo: SINTEF/Gry Karin Stimo.


K4
K8

Surprising climatic effects of bioenergy

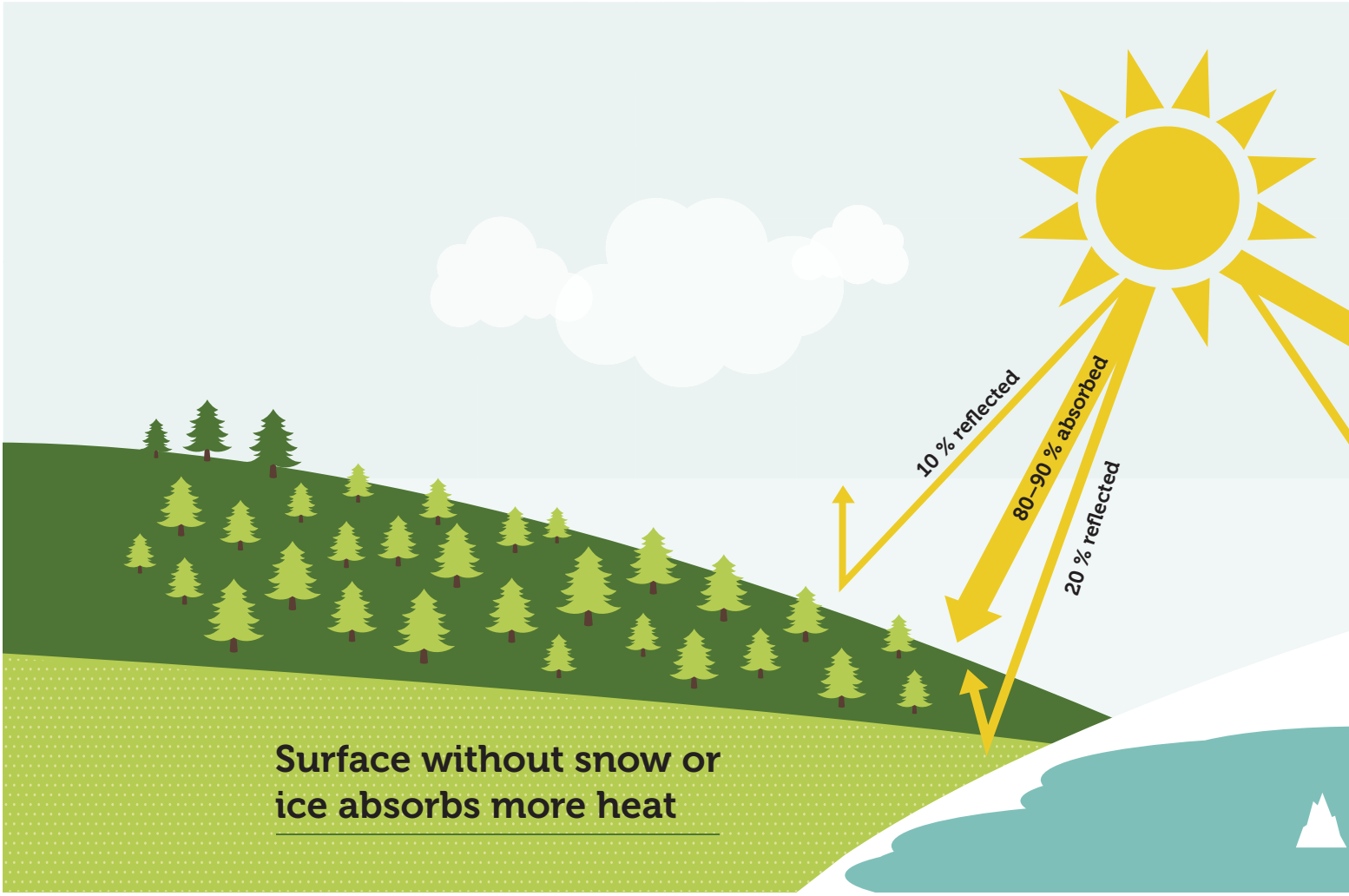
Did you know that in some parts of the world, people can contribute to global cooling by burning wood or woodchips?

Official climate accounting defines bioenergy as a 'climate-neutral' source of energy. "Both the EU and the US are beginning to consider this in new ways. CenBio research has shown that such innovative thinking is essential," says NTNU professor Francesco Cherubini.

Cherubini explains that the climatic consequences of CO_2 emissions from burning timber products are mainly determined by one single circumstance: the time it takes before the emissions are reincorporated into new forest growth, a process that can take several decades.

> In the long term, bioenergy derived from forest products will always have a smaller direct effect on the climate than fossil energy does

"Current European and US policy overlooks not only the time aspect, it also ignores the fact that local effects of felling trees can either reinforce or counteract the effects of CO_2 emissions. On a felled site with a significant amount of seasonal snow cover, the increase in reflected solar radiation can affect the climate



NTNU professor Francesco Cherubini giving his keynote presentation at the European Biomass Conference and Exhibition (EUBCE) 2016.
Photo: EUBCE.

in ways that largely compensate for the effects of the emissions from combustion," the NTNU professor points out.

Together with colleagues Anders Hammer Strømman and Ryan M. Bright, Cherubini has demonstrated that the use of biomass from central Canada for energy production can contribute to global cooling.

"There is no universal relationship as far as this effect is concerned. Climatic effects are dependent on location. But we need to remember something important, which is that in the long term, bioenergy derived from forest products will always have a smaller direct effect on the climate than fossil energy does. In Norway, it is also more climate-friendly in the short run to use energy derived from wood than from fossil sources. The same is true for other regions which, like us, experience a strong cooling effect from felled areas because they reflect a great deal of solar radiation," says Cherubini.

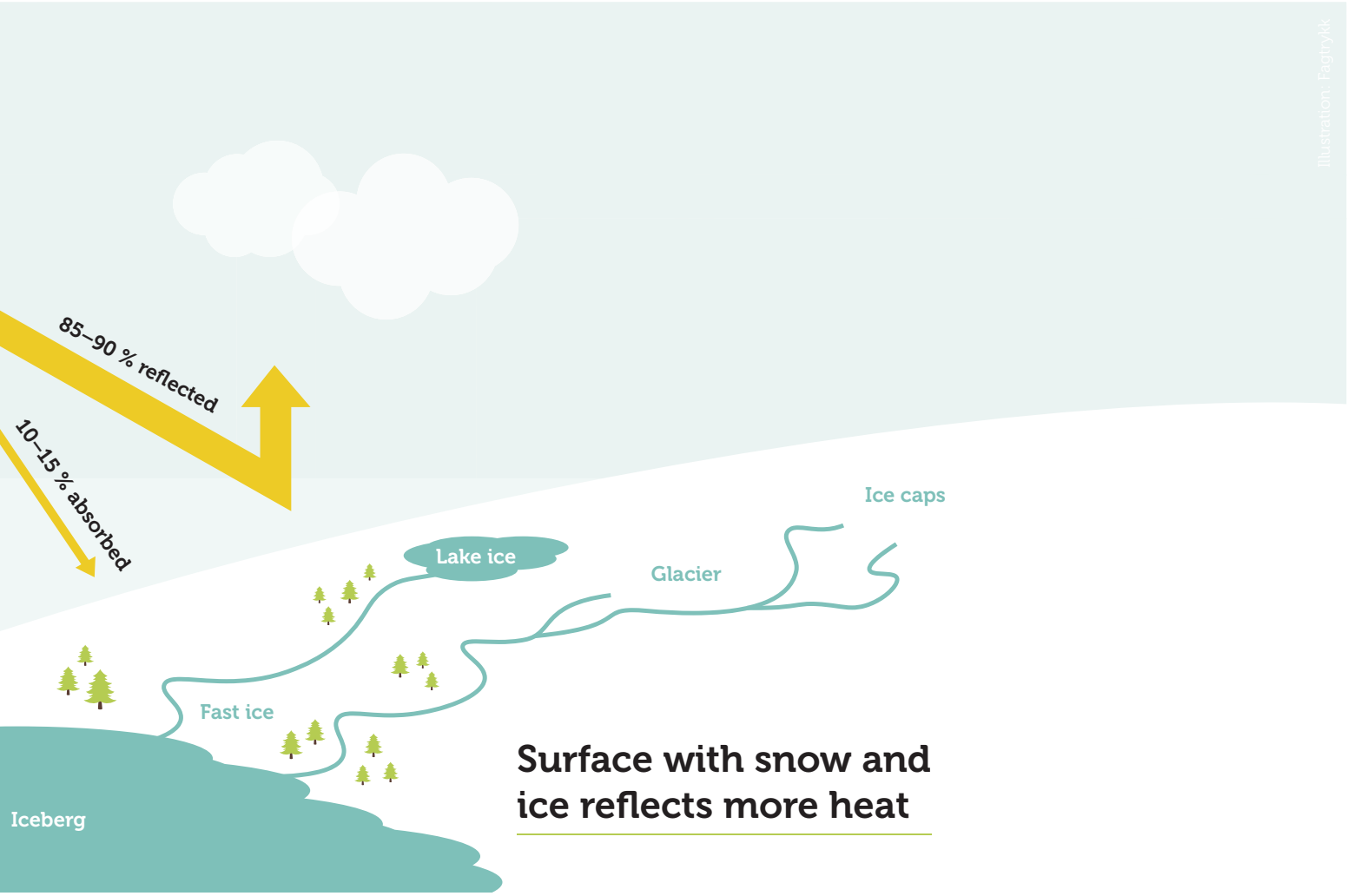


Illustration: Fagtrykk

Surface with snow and ice reflects more heat

The international CenBio

Although a Norwegian research centre, CenBio had an international outlook from day one.

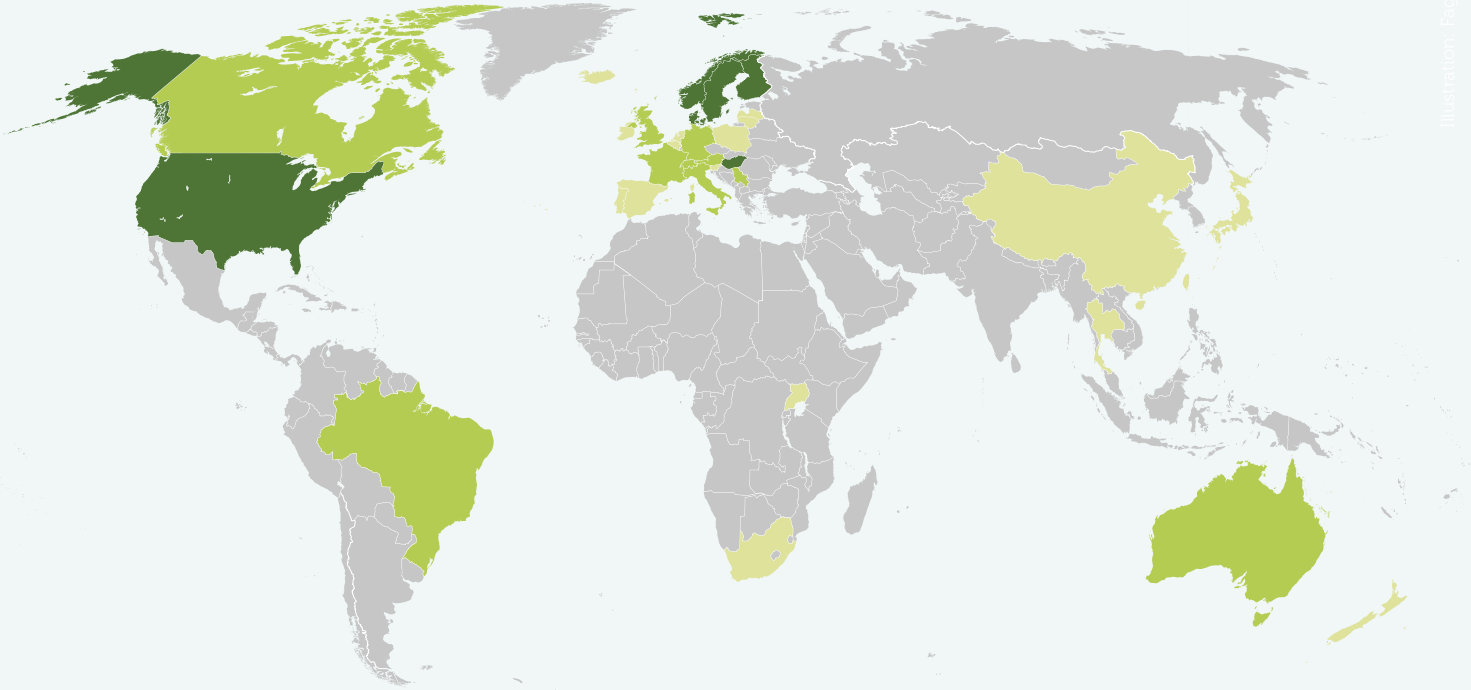
Although CenBio was largely focused on the Norwegian application of bioenergy research, the Centre consistently looked outward, not just to promote its results but also to seek expert involvement from research institutions internationally.

Some international partners were directly involved in the Centre's R&D activities, most notably the R&D unit and a biomass combustion plant of the Swedish energy company Vattenfall. They had developed a technical concept that improved CHP plant performance by reducing fouling, corrosion and emissions. The concept, called ChlorOut, needed further development work to put it into practice, especially with waste fractions such as demolition wood as fuels.

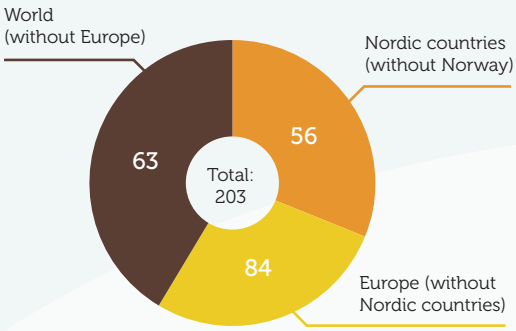
"When CenBio started, it presented us with an opportunity to build a prototype installation and use it to research and develop the technology through to maturity," says Håkan Kassman, Senior Technical Advisor at the Vattenfall spin-off company ChlorOut AB.

"Through CenBio, we have been able to install the prototype at a full-scale plant, and conduct a tremendous amount of

Vattenfall Jordbro power plant.
Photo: Vattenfall.



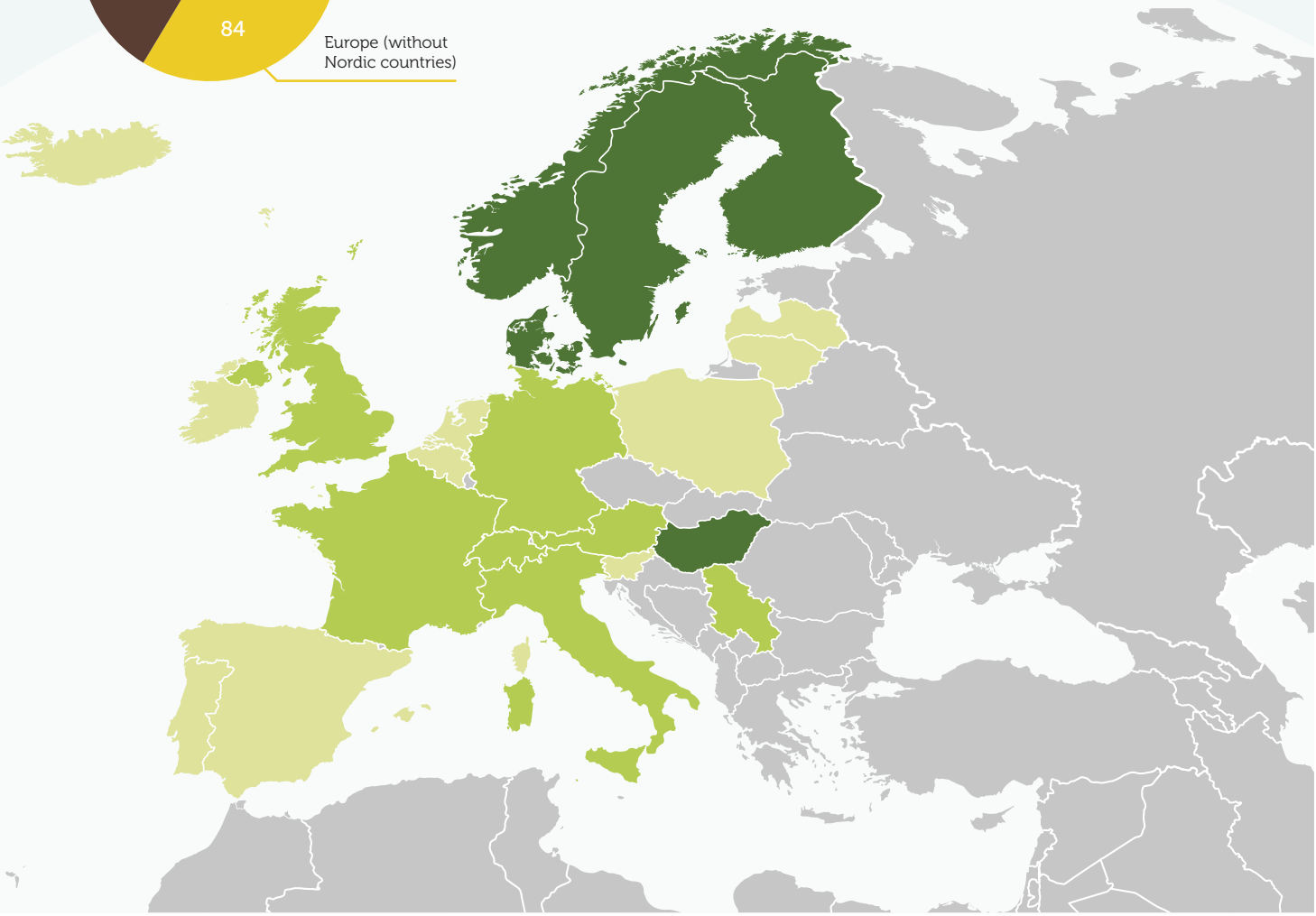
International collaborations leading to CenBio peer-reviewed publications



33 countries involved in CenBio publications

31 collaborations with the USA, with 16 organisations and universities

- 15 and more collaborations
- 4–14 collaborations
- 1–3 collaborations



useful experiments which have improved our knowledge of combined NOx and corrosion reduction," he adds.

The ChlorOut concept is a technical solution that reduces corrosion and deposit problems in both biomass- and waste-fired boilers. It also offers the possibility for simultaneous reduction of nitrogen oxides (NOx) in the flue gas, thus eliminating the need for traditional deNOx chemicals, which can be problematic from a health and safety perspective. The concept has also proved effective in reducing dioxin emissions.

Chief Scientist Øyvind Skreiberg from SINTEF Energy Research explains that the collaboration with Vattenfall had far-reaching benefits for the Centre. "It is a promising technology that Vattenfall has continuously tested and optimised in one of their own plants within CenBio. As such, ChlorOut brought unique capabilities into CenBio that strengthened the Centre. Vattenfall interacted with CenBio researchers with the aim of optimum utilisation of biomass fuels in combined heat and power plants."

International Collaborations & Conferences

CenBio has presented its work on more than 250 occasions at many international conferences throughout its 8-year life, including the European Biomass Conference and Exhibition (EUBCE), the International Conference on Chemical & Process Engineering, International Conference on Industrial Ecology and International Conference on Applied Energy. CenBio researchers have published peer-reviewed works resulted from collaborations with some of the most prestigious organisations in the world.

A Europe-wide strategy

Research and innovation plays a key role in achieving the fundamental transformation of Europe's energy system and responding to the objectives of the Energy Union.

In 2015, the European Commission launched an integrated strategic energy technology (SET) plan, in which the Energy Union's priorities have been translated into 10 priorities. Through a participatory process involving the European Commission, Member States, key industrial stakeholders and R&I actors, ambitious targets have been set for each priority, along with an implementation plan to improve technologies.

CenBio played an important role by organising, together with the European Energy Research Alliance Joint Program (EERA JP) Bioenergy, a workshop to discuss and define how bioenergy, as one of the 10 energy priorities, can contribute to a more sustainable, secure and competitive energy system in Europe. The workshop caught the attention of key European stakeholders representing the research community, industry and public authorities in the bioenergy sector.

The workshop caught the attention of key European stakeholders representing the research community, industry and public authorities in the bioenergy sector

"In my view, the strategy will only become meaningful when it is implemented", says Senior Research Scientist Berta Matas Güell, who has represented CenBio in the SINTEF Brussels office since November 2015.

Immediately afterwards, Matas Güell organised a second workshop to generate Horizon 2020 project ideas. Horizon 2020 is the biggest ever EU research and innovation program with nearly 80 billion Euros of project funding available from 2014 to 2020, in addition to the private

investments this money is expected to attract.

Besides facilitating the initiation of new Horizon 2020 proposals, the workshop also aimed to mobilize and engage European Centres of Excellence and strengthen cooperation between these centres and the EERA JP Bioenergy. Six project ideas were generated, of which two involved CenBio members.

It was the first time within the bioenergy field that national and European forces came together through the joint participation of the EERA Bioenergy team and three national Centres of Excellence on bioenergy in Europe.

After these two workshops, key European organisations in bioenergy got to know about CenBio, what it represents, the R&D priorities within the Centre and the infrastructure available.

Bioenergy workshop arranged by EERA JP Bioenergy and CenBio in Brussels in April 2016. Top: Senior Research Scientist Berta Matas Güell. Down: CenBio Centre Coordinator Marie Bysveen.
Photo: Michaël Becidan.

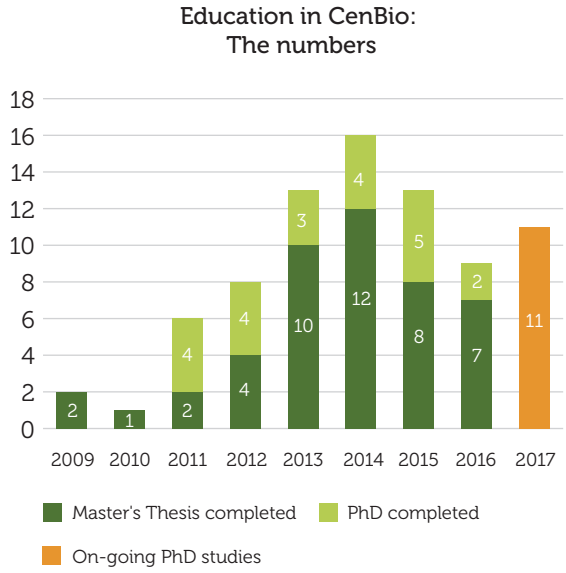
A bright future in Europe

"I hope to see this success as a stepping stone for more international collaboration, perhaps establishing several pan-European projects in the field of bioenergy research. The development of such relationships shouldn't stop with the end of CenBio."

Marie Bysveen, CenBio Centre Coordinator

Training the next generation

To ensure that Norway remains an active player in bioenergy research and innovation for decades to come, the training and development of the scientists and entrepreneurs of the future was a cornerstone activity for CenBio.



When academic institutions collaborate, you might expect educational needs to be taken care of. But careful planning and coordination was needed to ensure that the PhD candidates got the support and networking they need to succeed. The Bioenergy Graduate School was designed to solve this problem. Professor Terese Løvås explains how CenBio designed a solution for the 33 PhD candidates and 46 Master students involved with the Centre.

"In broad terms, the thought behind the Bioenergy Graduate School was to create a common syllabus between the two academic institutions, NMBU and NTNU. Each PhD candidate must take a set of courses and exams for the schooling element of their PhD. It is often a problem to find enough relevant courses at a single institution, so bringing the institutions together will create a wider range of quality options. This was especially relevant for students at NTNU, as NMBU offer several Master degrees in bioenergy topics."

Collaboration is key

To create the best possible experience for Master students and PhD candidates affiliated with CenBio, the team looked to facilitate collaboration not just between Trondheim and Ås, but across international borders too. In the early days of CenBio, Professor Johan Hustad (NTNU) worked hard to expand this

process and offer courses from Danish and Swedish institutes to early CenBio students. The Centre was strongly influenced by the CeCost Graduate School at the Swedish Centre for Combustion Science and Technology, and has actively sought links with the Nordic Five Tech (N5T) alliance. Anders Hammer Strømman had leadership of this activity up to the mid-term evaluation, and Terese Løvås took over the role once Anders became leader for the value chain analysis activity.

"We have since focused on building activities to offer to all students affiliated with CenBio. We have hosted networking events and workshops where we don't discuss science but rather their working situation," explains Løvås.

relevant to the CenBio value chains.

"The aim of my research was to look at the potential of using different biomass waste products as a phosphorous fertiliser instead of mineral fertiliser which comes from mines," she says. "I looked at two types of wood ash and digestates, the residue from the biogas process, both of which were relevant and interesting for other CenBio research."

> The team looked to facilitate collaboration not just between Trondheim and Ås, but across international borders too

Eva successfully defended her PhD thesis 'The recycling potential of phosphorus in secondary resources' in June 2016 and now works as a Research Scientist at NIBIO.

Having joined half-way through the life of CenBio, Løvås has some thoughts on how things could have been set up differently from the beginning. "Facilitating common courses was successful to a point, but there's certainly more that could have been done when we look at the success of the CeCost Graduate School in Sweden."

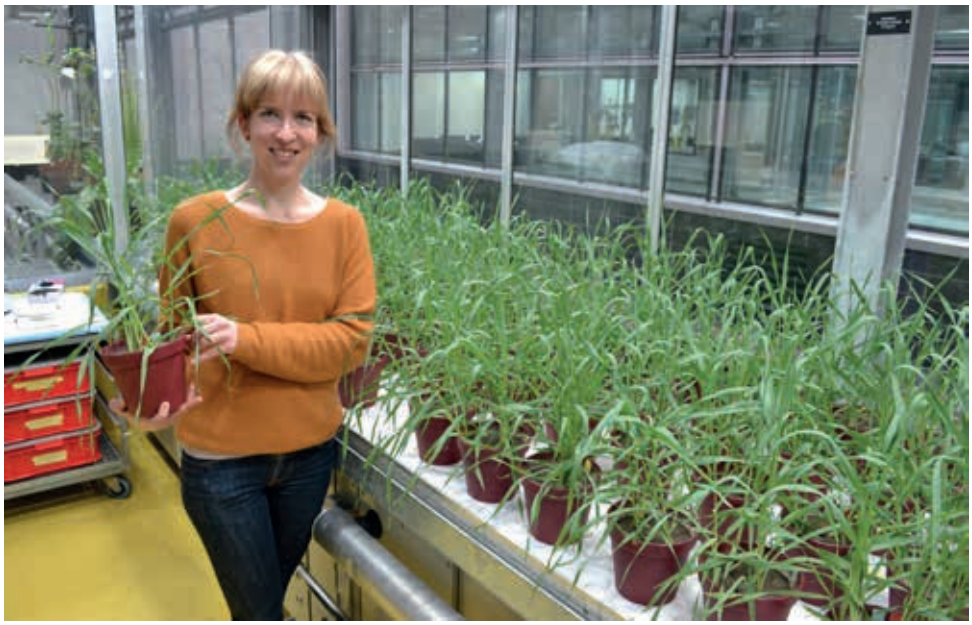
"It's also of critical importance to pull the students and PhD candidates into the work of the Centre as much as possible. It is helpful for the work package leaders to gain extra resources, but most of all to give the students a feeling of relevance and expose them to our user partners for networking opportunities. This doesn't just happen by itself, it has to be carefully planned and managed."

With many spin-off projects launched thanks to the work of CenBio, there should be many opportunities to put these lessons into practice.

A diverse group of researchers

A subset of PhD candidates was fully funded by CenBio and therefore worked closely with the Centre's work packages, while others were partly funded and only involved at arm's length.

Dhruv Tapasvi played a key role in the study of biomass torrefaction in Trondheim, and took advantage of the close links between NTNU and SINTEF to complete his research. In contrast, only a part of Eva Brod's PhD work fell within the focus areas of the Centre, though she collaborated with NTNU on her scientific papers that were



NIBIO research scientist Eva Brod experimenting with phosphorous fertilizer during her research exchange in ETH Zurich.
Photo: Trond Knapp Haraldsen.

Attracting talent to Norway

Attracting key talent is an important aspect of any research programme. It is even better when they choose to stay afterwards.

Attracting key talent is an important aspect of any research programme. It is even better when they choose to stay afterwards.

A perfect storm

With a Master degree in Agricultural and Biosystems Engineering from North Dakota State University, the USA's agricultural heartland, Dhruv was working as a process engineer in Minnesota but struggling to see a path forward.

"Although my wife is Indian she had grown up in Norway, so we decided to look for opportunities here. Since my academic experience was very relevant to biofuels and biomass, this opportunity was the perfect fit for me."

Dhruv Tapasvi, the day of his PhD defence.

Photo: Ehsan Houshfar.

A varied programme

Once Dhruv arrived at NTNU in January 2010, he quickly saw the benefits of taking a PhD under the CenBio umbrella. His initial work focused on studying biomass torrefaction to improve the properties of biomass as a fuel, which eventually led to his PhD thesis: 'Experimental and Simulation Studies on Biomass Torrefaction and Gasification.'

"Due to the collaboration between NTNU and SINTEF, I didn't have to spend much time developing equipment. Instead I could focus more on investigating how the torrefaction can be applied to Norwegian biomass like spruce and birch. We designed around 16 different biomass torrefaction experiments."

International exposure

A year after starting his PhD study, Dhruv presented his review paper on biomass torrefaction at the 9th European Conference on Industrial Furnaces and Boilers. During his time with CenBio, Dhruv participated in many conferences, including presenting a kinetic study at the 20th European Biomass Conference and Exhibition.

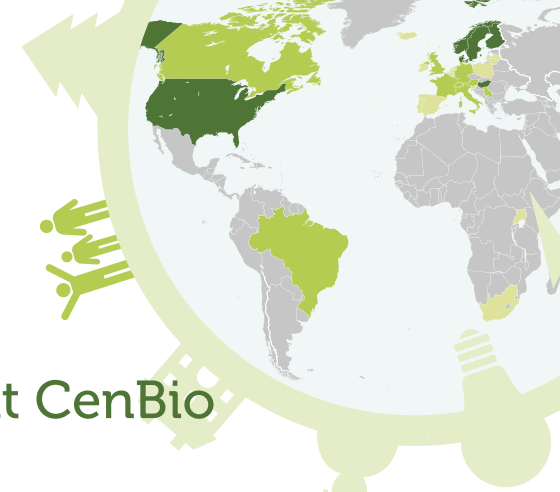
This was a result of a successful collaboration with a chemical kinetics expert at the Hungarian Academy of Sciences. "I got in touch with Gabor Varhegyi as he had developed interesting micro-level kinetics software. We conducted experiments in a thermogravimetric analyser (TGA) in cooperation with Gabor and I wrote a couple of scientific papers on decomposition kinetics of woods in different environments."

Attractive to industry

As Dhruv moved towards the end of his three-year CenBio stipend, he began to look for jobs. He soon found FMC BioPolymer, a company in Haugesund making biopolymers from Norwegian seaweed. They sought an expert in R&D with a background in biomass and engineering.

"They really valued my work in kinetics and especially the simulation work I did during my studies. No one here had the expertise in that area so I stood out thanks to my time with CenBio."

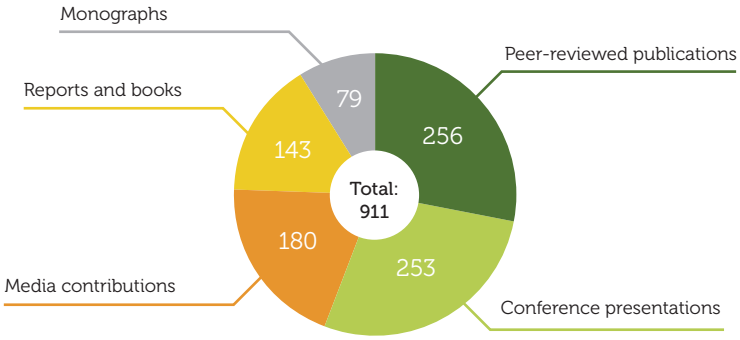
But Dhruv values more than just this successful outcome from his time with CenBio. "The SINTEF researchers were friendly, my supervisors supportive, and their doors were always open."



Letting the world know about CenBio

The number of peer-reviewed publications and media appearances throughout the Centre's eight-year life was a major success story for CenBio.

Communicating our results to the rest of the world



More than 900 peer-reviewed publications, media contributions, monographs, reports, book chapters, and conference papers and presentations helped spread the work of CenBio.

CenBio in the media

In a 2013 article in the New York Times entitled 'A City That Turns Garbage Into Energy Copes With a Shortage', EGE Oslo's Waste-to-Energy (WtE) activities were communicated, including praising the energy and environmental benefits. The future of the WtE business at the European level was also discussed in depth with several interesting insights from EGE Oslo.

Other outstanding media contributions from CenBio included (*all links available on* ***www.CenBio.no***):

Nasjonal Vedkveld - NRK

(National wood burning evening)

CenBio research scientists Morten Seljeskog and Simen Gjølsjø were guests on a firewood evening at the Norwegian broadcaster NRK, sharing tips on burning wood logs in residential stoves.

SINTEF research scientist Morten Seljeskog and NIBIO senior advisor Simen Gjølsjø at NRK's Nasjonal Vedkveld.

Photo: Facsimile NRK.

Den gode veien fra hogstavfall til bioenergi – Forskning.no

(The right path from forest residues to bioenergy)

Research Scientist Kjersti Holt Hanssen (NIBIO) shared the results of her work on forestry methods showing how to optimise the logging of forest residues while ensuring a sustainable forest growth.


forskning.no

Kultur Helse Miljø Samfunn Teknologi Naturvitenskap I Blogg Meninger

Den gode veien fra hogstavfall til bioenergi

KRONIKK: Greiner og topper som ligger igjen etter tømmerhogst kan være en viktig kilde til bioenergi, men gjør vi det på feil måte kan vi risikere at skogen vokser dårligere i fremtiden, skriver Kjersti Holt Hanssen i denne kronikken.

Kjersti Holt Hanssen

Photo: Facsimile Forskning.no.

EGE Oslo and CenBio research scientist on French/German TV

SINTEF senior research scientist Michaël Becidan was interviewed by the French/German TV channel ARTE commenting on Oslo's advanced waste treatment system and its process of converting waste to energy. The interview was hosted by EGE Oslo (Klemetsrud plant).

SINTEF senior research scientist Michaël Becidan on ARTE's French/German TV programme.

Photo: Facsimile ARTE.

Se hvordan kloakk fra 4,5 millioner amerikanere forvandles til gjødsel og strøm - Teknisk Ukeblad

(See how the sewage of 4.5 million Americans gets converted into fertilizer and electricity)

The leading technology magazine in Norway featured a story on how technology from CenBio user partner Cambi treats sewage from 4.5 million residents of Washington DC and transforms it into fertiliser and electricity.

Photo: Facsimile TU.no.

Ny teknologi: – Glem alt du har lært om biogassproduksjon

(New technology: forget everything you have learnt about biogas production)

CenBio user partner and Biogas Innovation Award winner Antec Biogas was profiled in Norway's leading technology magazine. The story presented their biofilm reactor that doesn't require high pressure, high temperatures or large amounts of energy, thus halving production costs compared to competing processes.

Photo: Facsimile TU.no.

Tre tips gir skikkelig fyr i peisen – Klikk.no

(Three tips to make a proper fire in your stove)

Morten Seljeskog from SINTEF Energy Research was featured in this Norwegian lifestyle publication sharing tips on how to light a wood stove correctly to avoid pollution and the risk of a chimney fire.

Photo: Facsimile Klikk.no.

In addition to international media mentions, CenBio researchers were encouraged to share their insights through several channels closer to home, including the SINTEF Energy blog and Gemini.no.

A united front in Europe

CenBio presented a united front at the 24th European Biomass Conference and Exhibition (EUBCE), one of the world's leading events on the entire biomass value chain, in June 2016.

"It is something we started to plan more than a year beforehand. 24 abstracts were submitted by CenBio members and we were represented with a workshop, poster presentations and oral presentations covering the whole CenBio value chain with all areas represented," says a proud Odd Jarle Skjelhaugen.

A CenBio stand in the exhibition area facilitated further dialogue with bioenergy researchers and industrial actors joining the conference, while NTNU professor Francesco Cherubini was offered a spot in a plenary session. Several PhD candidates were also involved.

A reputation earned through CenBio

NTNU professor Anders Hammer Strømman and his group contributed to the 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC). He also made a presentation for the Norwegian Ministry of Environment, on the influence of bioenergy in the mitigation of climate change, drawing many conclusions from the Centre's life cycle assessments.

"CenBio research made this contribution possible," says Strømman. "The papers published from CenBio between 2010 and 2012 began to give us an international reputation, which led to an invitation to participate in the IPCC report. A lot of our early work focused on the fundamentals of bioenergy and its impact on climate

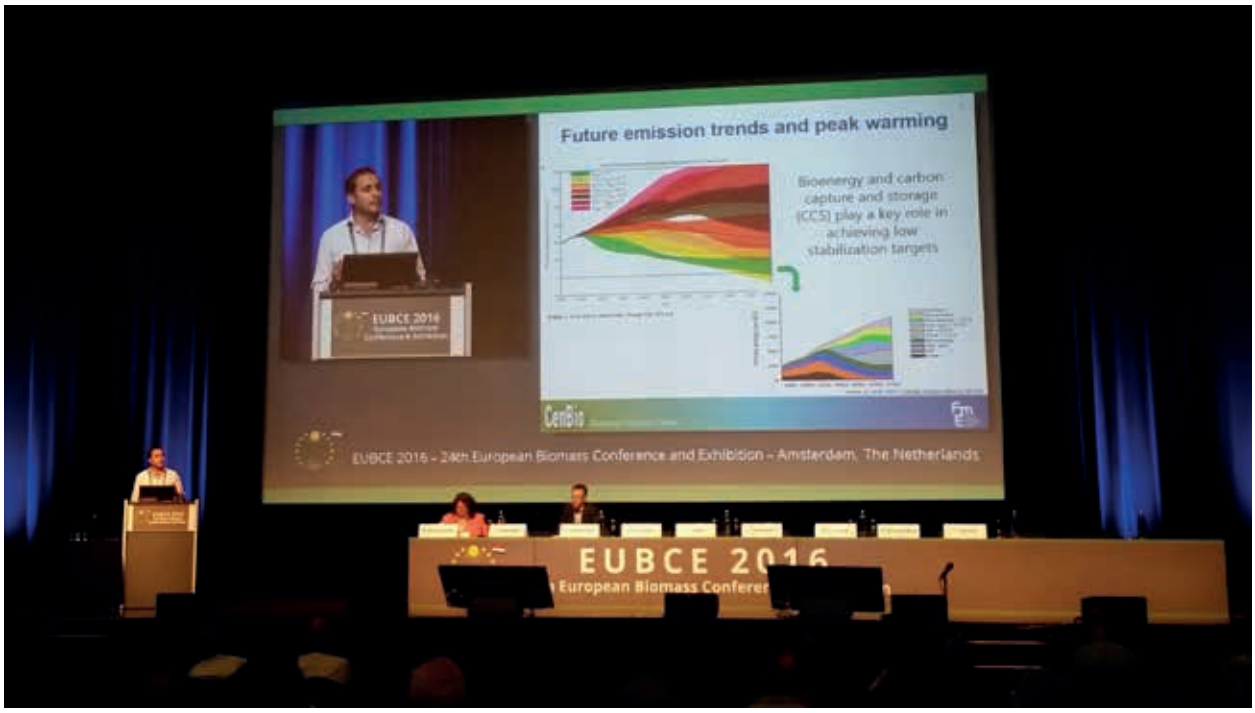
CenBio stand at the EUBCE 2016, featuring from left: Bård Hansen (Prediktor AS), Liang Wang (SINTEF), Odd Jarle Skjelhaugen (NMBU) and Line Rydså (SINTEF).

Photo: EUBCE.

change, so it was a natural fit for the third working group of the report, which focused on mitigation."

The contribution to such a high-level international body helped CenBio gain further international recognition and put Norway on the bioenergy map.

The papers published from CenBio between 2010 and 2012 began to give us an international reputation



Keynote presentation by NTNU professor Francesco Cherubini at the European Biomass Conference and Exhibition (EUBCE) 2016.

Photo: CenBio.

The **Intergovernmental Panel on Climate Change** (IPCC) is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. IPCC assessments are written by hundreds of leading scientists who volunteer their time and expertise as coordinators and lead authors of the reports.

In 2007, the Nobel Peace Prize was awarded jointly to the IPCC and Al Gore for "their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

Meeting the overarching goals of Norwegian research

Trond Værnes, Special Advisor at the Research Council of Norway talks to us about how CenBio has contributed to their goals for the FME programme.

What was the status of bioenergy research before CenBio?

The 2009 Parliament climate agreement in Norway laid the foundation for a significant increase in R&D investment in environment-friendly energy, setting this as the most important single measure to reduce greenhouse gas emissions. Bioenergy and energy recovery from waste were some of the fields that received a large increase in R&D investments. The reasoning was that Norway has large untapped biomass resources, particularly in the forestry sector.

Ceremony of the Bioenergy Innovation Award 2016, in Amsterdam, June 2016. From left: Trond Værnes (Research Council of Norway), Uno Andersen (Antec Biogas), Egil Andersen (Antec Biogas).

Photo: CenBio.

In practice, the utilization of forest waste and low quality wood for bioenergy was very low. Norway had modern energy recovery technologies, but the need for optimization and thereby reducing environmental emissions was substantial. There was also a need to start exploiting wet organic waste in Norway. Documenting environmental benefits and setting the framework for a more intensive utilization of biomass were both considered very important.

Research fields within bioenergy that received increased funding were:

- Cooperation between biology and technology research
- Ecology, climate and environmental issues in a bioenergy context
- Utilizing wet organic waste and manure for biogas production
- Energy recovery from waste

In addition, the Research Council of Norway had initiated a foresight process about the production and use of biofuels in Norway.

What is your view on the CenBio Centre?

At the time of the announcement of the first FME scheme, the research groups in Trondheim and Ås sent one application each. However, the Research Council strongly recommended a cooperation between technology research and biomass research. R&D and industry players responded to this and agreed on one common initiative, giving birth to FME CenBio. The application was very good and the way it was implemented is well described in this report.

The Research Council is very thankful to both R&D and industrial players for their outstanding inputs during CenBio, having been essential for Norway. The Norwegian bio-energy sector has been through difficult times during CenBio's period, for example when the Norwegian pulp and paper sector was hit by a crisis. This changed the framework for the development of the Norwegian bioenergy sector, although today it is seen as a clear opportunity for the Norwegian biofuel industry.

CenBio has laid the foundation for a modern way of utilizing biomass residues and waste

CenBio has laid the foundation for a modern way of utilizing biomass residues and waste. Together with the bioenergy user partners, CenBio research has laid the trails that many others will follow and benefit from for many, many years to come.

The Research Council of Norway

The Research Council of Norway serves as the chief advisory body for the government authorities on research policy issues, and distributes roughly 9 billion Norwegian kroner to research and innovation activities each year. The Research Council works to promote international cooperation and increased participation in the EU framework programmes on research and innovation. The Research Council creates meeting places and provides a platform for dialogue between researchers, users of research and research funders.

FME's Explained

The Centres for Environment-friendly Energy Research scheme (FME) has been established to finance time-limited Centres, which conduct concentrated, focused and long-term research of high international calibre to solve specific challenges in the fields of renewable energy, energy efficiency, social sciences and CO_2-management. The research activity is carried out in close cooperation between prominent research communities and users.

Cooperation with industry, and each other

From finding common ground to exploring new ways of working together, everyone involved in CenBio quickly learned that collaboration was an essential ingredient for success.

CenBio participants to the CenBio Strategic Days 2015 at the visit of the Statkraft Varme Waste-to-Energy plant in Heimdal.
Photo: CenBio.

CenBio brought researchers and industrial professionals together with the aim to build value creation from Norway's bioenergy challenges. In many cases competitors began to work together for the first time, in both the academic and industrial space.

Cooperation with industry

Nineteen companies were involved in CenBio throughout the eight-year life of the Centre, ranging from multinational power companies to small manufacturers. The transfer of knowledge and experience worked both ways and left a lasting legacy for the bioenergy research in Norway.

> There was a positive collaboration and very few topics divided us

Vattenfall in Sweden worked in close cooperation with SINTEF Energy Research through both their R&D unit and bioenergy plant. The work conducted on the Vattenfall ChlorOut technology for combined NOx and corrosion reduction meant Vattenfall brought unique capabilities into CenBio that strengthened the Centre.

"Vattenfall dedicated a full-scale plant throughout the eight years for studies on corrosion protection," explains Chief Scientist Øyvind Skreiberg of SINTEF Energy Research. "Within CenBio, they have developed their ChlorOut system at the plant from initial studies and installation to full measurement campaigns and verification of the concept."

"We have also seen strong collaboration with wood stove manufacturers on very specific aspects such as afterburners for soapstone stoves to reduce emissions. Working with small producers

has allowed us to see these processes through from idea to production."

Some partners also played an active role in setting the strategic goals for the Centre. Former SINTEF research scientist Morten Fossum now works as Vice President Development at Statkraft Varme in Trondheim. In addition to overseeing the measurement campaigns and combustion modelling work for the Statkraft Varme Marienborg plant in Trondheim, Morten sat on the Executive Board representing not just his company, but all user partners.

"Bringing different research institutes together with industry is not a natural marriage and so it took time to figure out the best ways of working together. I feel the range, experience and motivations of the user partners was well-balanced, there was a positive collaboration and very few topics divided us."

"We also see that many in the research community are now more aware of the practical challenges faced by industry, and the solutions required to solve them."

Statkraft Varme, Hafslund Varme and Akershus Energi shared data and experience concerning heat production from liquid biofuels. NMBU research scientist Per Kristian Rørstad and SINTEF research scientist Gonzalo del Alamo Serrano merged this knowledge with scientific and market information. "The result is a guide for how to reduce operational problems and feedstock costs," says Cato Kjølstad from Hafslund Varme.

Cooperation with each other

The cooperation within CenBio took several years to bear fruit. Prior to the creation of the centre, little collaboration had taken place between the Trondheim researchers of SINTEF and NTNU, and the research teams at NMBU and NIBIO at Ås. It took time for relationships to form and the bumps in the cooperation processes to be ironed out.

Odd Jarle Skjelhaugen, Deputy Centre Coordinator based at NMBU, explains: "The day-to-day collaboration has undoubtedly improved over time. The groups from NMBU and NIBIO led several sub-projects earlier in the bioenergy value chains, from harvesting and transporting biomass to studying the quality of the feedstock and wood chips."

"This information was then used to analyse the product as fuel for district heating plants at SINTEF and NTNU in Trondheim, from the perspectives of efficiency, emissions and the quality of ash produced. By merging the scientific and industrial data and competence, we could analyse the sustainability of complete value chains. With hindsight, it was always going to take time to find the best areas for cooperation."

> But the 8-year timeline made it possible to stay patient and do the right things without pushing for immediate results

SINTEF senior research scientist Michaël Becidan presented the results of the collaborative work on Waste-to-Energy on

CenBio participants at the CenBio Days 2014 visiting Akershus EnergiPark.
Photo: CenBio.

French & German television at the EGE-Klemetsrud Waste-to-Energy plant. It was a special highlight for Centre Coordinator Marie Bysveen: "I was incredibly proud to see excellent research that was very much a partnership between Trondheim and Ås get such valuable international exposure."

"The long-term nature of the project has been very important for the success of the collaboration. Of course, you can achieve a lot in less time, but the 8-year timeline made it possible to stay patient and do the right things without pushing for immediate results. It has been a very positive experience for everyone involved."

Oiling the cogs of collaboration

If the research groups in Trondheim and Ås and the user partners were the three big cogs in the Centre, the CenBio days were the oil that kept things moving in the early days and accelerated progress towards the end.

Held once or twice a year throughout the life of the Centre, these day-long events brought together the different stakeholders of CenBio to focus everyone's attention on the Centre's achievements, sharing results, and discussing next steps.

Bringing people together in one room on a regular basis was a key success factor in the project, says Marie Bysveen: "There were cultural challenges to overcome, not just between research and industry but between SINTEF's business focus and the more academic focus of NTNU and NMBU. The results speak for themselves. I will always remember the moment in a meeting room at Oslo Airport when we switched the CenBio focus to value chains. The discussion was very open and created a solid basis for moving forward with the second half of the Centre's work."

NIBIO research scientist Linn Solli in the Biogas Lab at Ås Campus.
Photo: Ove Bergersen.

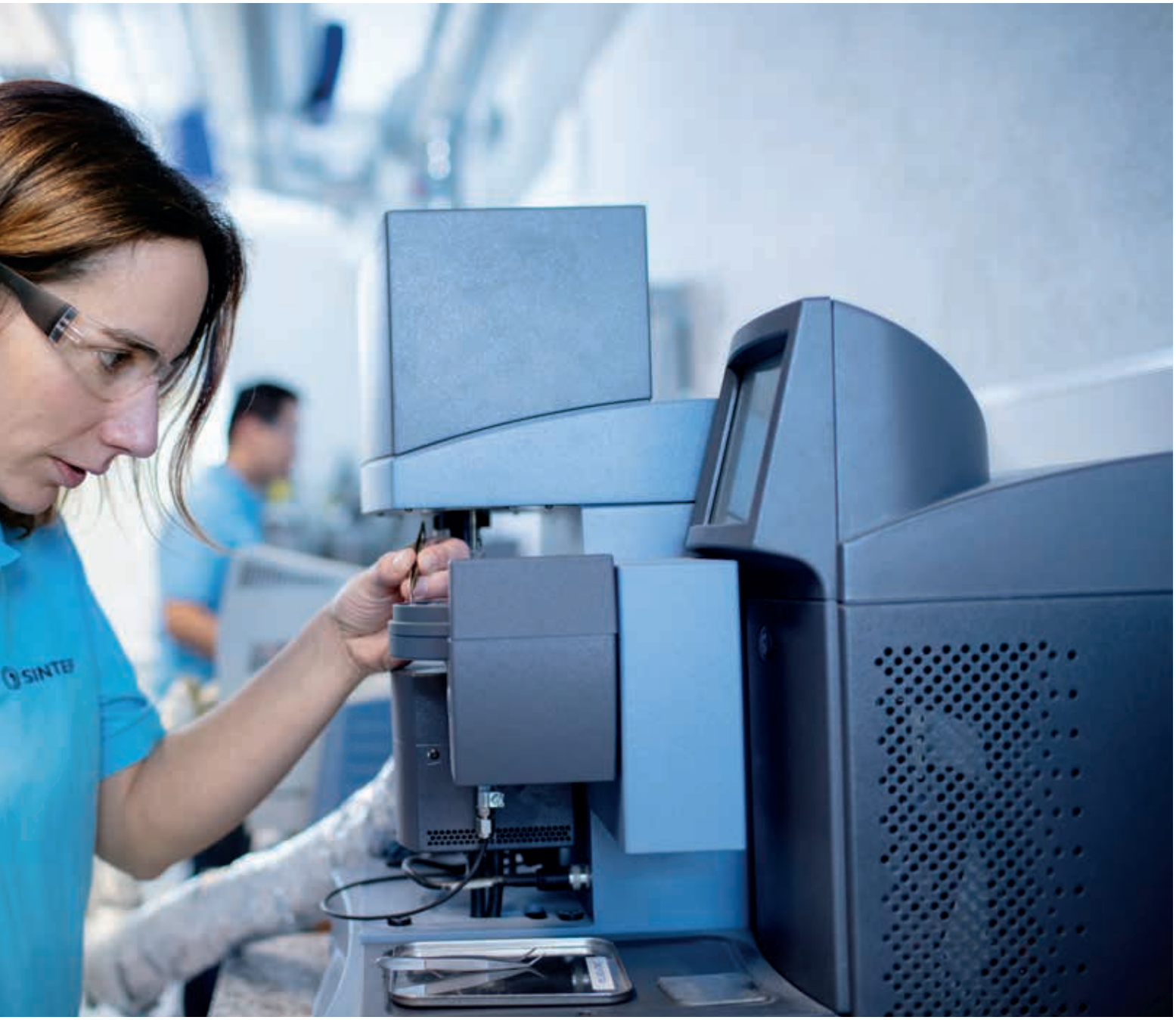
A legacy of infrastructure

Another important aspect in creating opportunities for cooperation between Trondheim and Ås was the purpose-built laboratories in both locations, infrastructure which will live on long after CenBio.

Most CenBio experiments were conducted in dedicated laboratories:

- Biochemical conversion lab (Ås)
- Biogas lab (Ås)
- Thermochemical conversion lab (Trondheim)
- Forest biomass lab (Ås)

One example is the Biogas lab at Ås. Tormod Briseid, NIBIO, looks after the lab, which was extended thanks to funding from CenBio. "As our labs handle waste, manure and sludge, it is not feasible to house them within regular office buildings because of the hygiene risks and odours. CenBio has enabled us to expand these facilities," says Briseid.



SINTEF research scientist Judit Sandquist operating a TGA (Thermogravimetric analyser) for assessment of thermal conversion behaviours of biomass and waste feedstocks under well-controlled conditions.

Photo: SINTEF/Geir Mogen.

The journey through the lab begins with the waste handling area, where material is sorted and prepared. The reactor hall contains more than 20 reactors equipped with different measuring systems.

Typical working amounts range from 5 to 20 litres, and measurements are taken every hour with temperature and pH levels closely monitored. The lab also features a 'clean' section, where samples can be analysed using microbiology and molecular tools and techniques.

Pål Jahre Nilsen from Cambi AS says the investment in infrastructure has been fantastic for them. "It is important that we now have a reliable analytical infrastructure. The biogas laboratory helps us get the data we need to be credible and competitive in the market. We have funded some test rigs ourselves and now consider NMBU as our research campus, something which was not the case 8 years ago."

As relationships across the Centre blossomed, researchers from both locations exchanged biomass samples, leading to joint publications.

A sustainable view of waste

The Norwegian Waste-to-Energy industry is at a crossroads. The concept offers unique advantages to Norwegian society but challenges lie ahead.

Waste-to-Energy (WtE) plants have a dual objective to reduce the volume and weight of waste (before ash is sent to landfill) while producing useful heat and/or power.

WtE is gaining increased importance in the energy mix of several European countries and Norway is no exception. Energy recovered from waste currently represents the main energy source of the Norwegian district heating system, having more than doubled to around 5 TWh/year since 2009. Half of the energy from WtE is considered renewable in national statistics, so the sector is contributing to the national renewable energy target.

The Norwegian WtE sector has been a growing industry for the last decade, increasing from a total capacity of about 1 million tonnes/year at the start of CenBio to 1.7 million tonnes today. 17 plants - all members of Avfall Norge, the Norwegian Waste Management and Recycling Association - are spread across Norway with an average waste throughput of 90% of their annual capacity, yet several Norwegian WtE plants are currently suffering from low profitability due to competition from Swedish plants. Several thousand tonnes of waste are exported from Norway to Sweden every year. The Scandinavian processing capacity exceeds the waste produced in the region.

1.7 million tons

municipal solid waste converted to energy in Norway.
(source: Avfall Norge, 2016)

Ashes transported to landfills

- Municipal Solid Waste (MSW) and residual waste
- New types of waste fractions: clinical waste, car fluff, etc. ...

Waste transport

Waste-to-Energy plant

Hot water circulating in district heating network

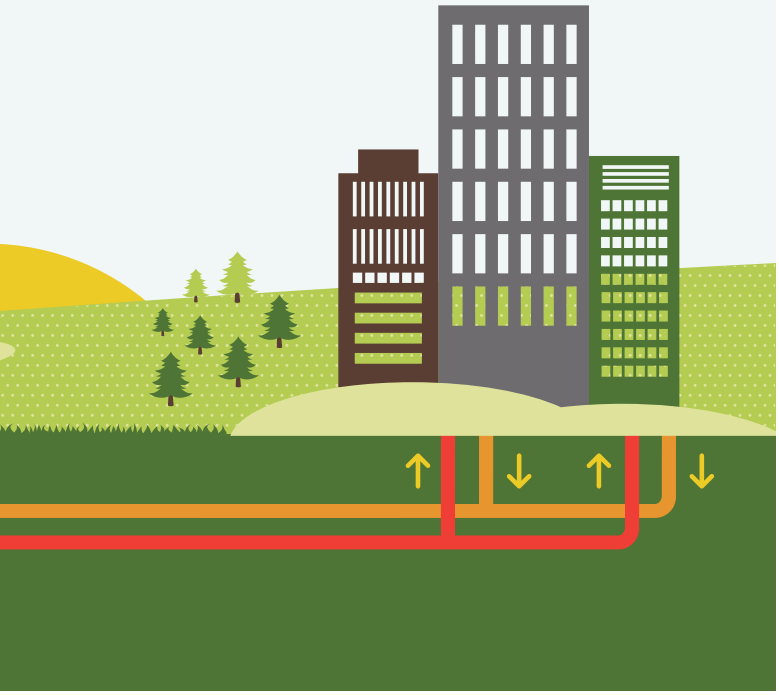
"A market with excess capacity will put the gate fees under pressure, which is not financially viable in the long run," says Hans-Olav Midtbust, General Manager at Energos.

"The two alternatives are to reduce the processing capacity by closing down plants, or increase the demand. An increase in demand for processing capacity can be achieved by importing waste from markets with insufficient capacity, as currently done by EGE Oslo who import waste from the UK, or by the insertion of often challenging new waste fractions," add Hans-Olav Midtbust and Francesco Cherubini (NTNU).

The Waste-to-Energy value chain

A life cycle assessment (LCA) and technology evaluation were used to assess the whole WtE value chain. This research activity was a collaboration between NTNU, NMBU and SINTEF. Emissions were traced throughout the life cycle stages from waste logistics to final disposal of the ashes. In addition, the plant model together with user partner data on the input waste, air and water

Waste-handling cranes at Statkraft Varme's Waste-to-Energy plant in Heimdal.
Photo: Alexis Sevault.

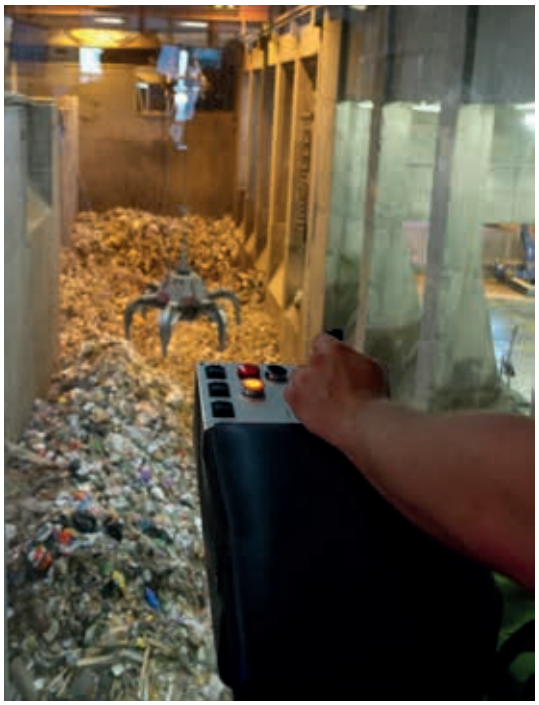


What's in municipal solid waste?

emissions and ash composition are used to assess the influence of a change in waste composition on the environmental performance of a WtE plant in a Norwegian context.

Ongoing start of waste combustion in one of Statkraft Varme's grate combustion chambers.

Photo: Statkraft Varme.



Waste-handling crane in operation in Statkraft Varme's Waste-to-Energy plant in Heimdal.

Photo: Alexis Sevault.

Such new waste fractions could potentially increase revenues or replace revenues from waste fractions no longer available (i.e. being processed differently or elsewhere).

Such new waste fractions could potentially increase revenues or replace revenues from waste fractions no longer available

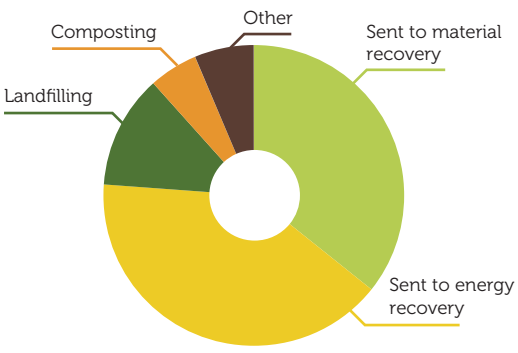
The Statkraft Varme plant in Heimdal outside Trondheim was used as a case study, in close collaboration with Morten Fossum and Egil Evensen from Statkraft. "Waste incineration is a part of the waste treatment system and the plants must be prepared to handle new waste fractions due to changes in the upstream waste treatment in a sustainable way," says Fossum.

The environmental performances of WtE systems were benchmarked against those of fossil energy systems. WtE performed better in most environmental impact categories, including climate change, although some trade-offs exist, such as higher impacts on human toxicity potential than natural gas, but lower than coal.

"The insertion of challenging new waste fractions is an option to both cope with the excess capacity of the Scandinavian WtE sector and to reach Norway's ambitious climate and energy goals," explains Francesco Cherubini.

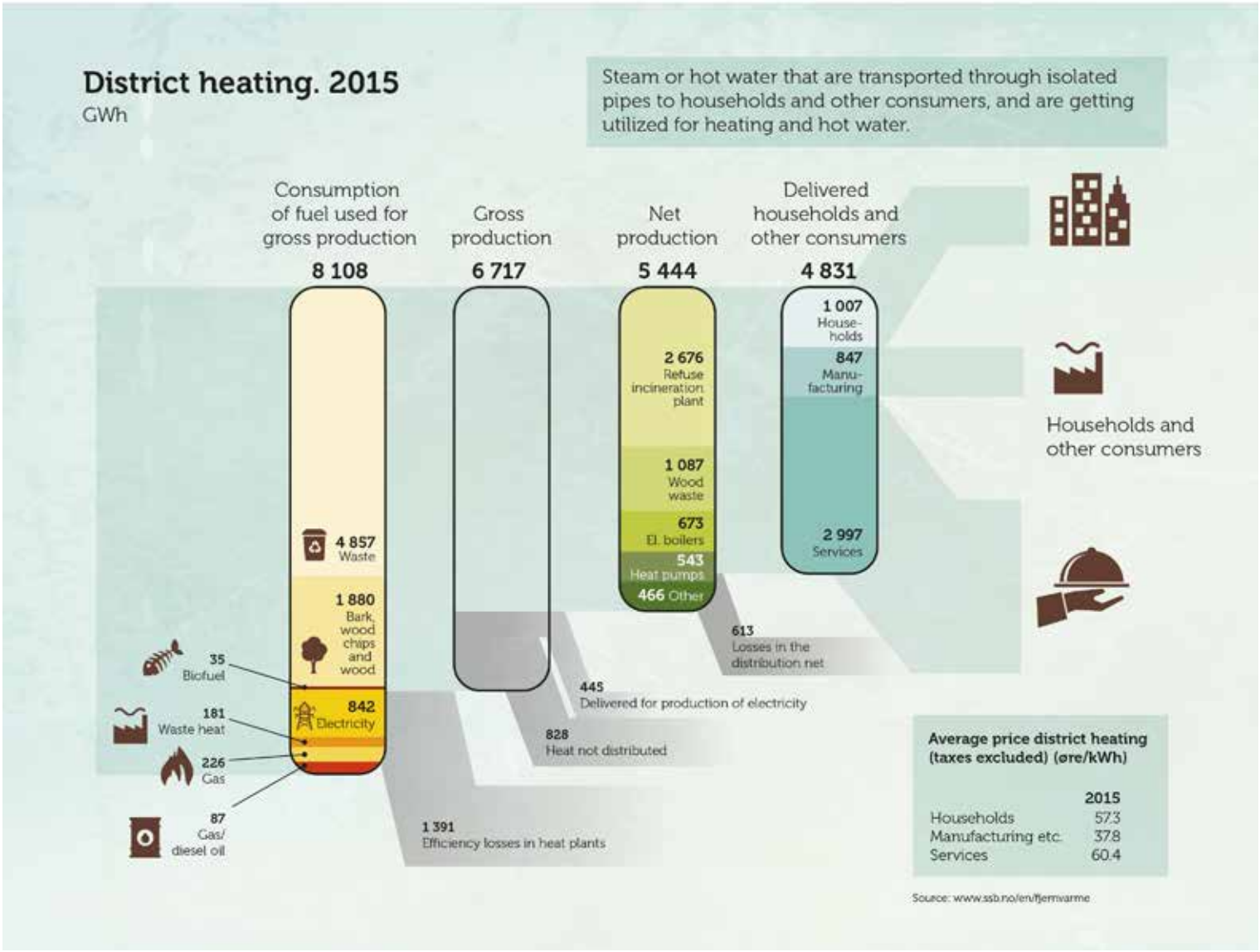
Looking ahead to 2030

SINTEF Energy Research, Statkraft Varme, Hafslund, EGE Oslo and Energos co-authored a peer-reviewed conference article and a poster presentation addressing the opportunities and challenges for the Norwegian WtE market. It was presented at the International Conference on Chemical & Process Engineering (ICheaP12) held in Milan, Italy, in 2015.



Norway's management of municipal solid waste is characterised, like all Nordic countries, by high levels of material and energy recovery, while keeping landfilling at a low level.

Source: SSB 2013.



"It was a first for us to produce a presentation not based so much on experiments or modelling, but to involve the industry in a far-reaching analysis of the future. Extensive cooperation between R&D and industry in writing an article is not that common. It was a very interesting experience, and everyone was pleased with the result," says Michaël Becidan from SINTEF Energy Research.

In addition to technical details, the poster presentation gave important background information on the energy market in Norway. For example, despite Norway's reputation as an oil and gas giant, about 95% of Norwegian electricity is generated from hydropower. After electricity, the demand for heating in households is met by wood stoves. District heating is number three, although this only accounts for a very small percentage of the total.

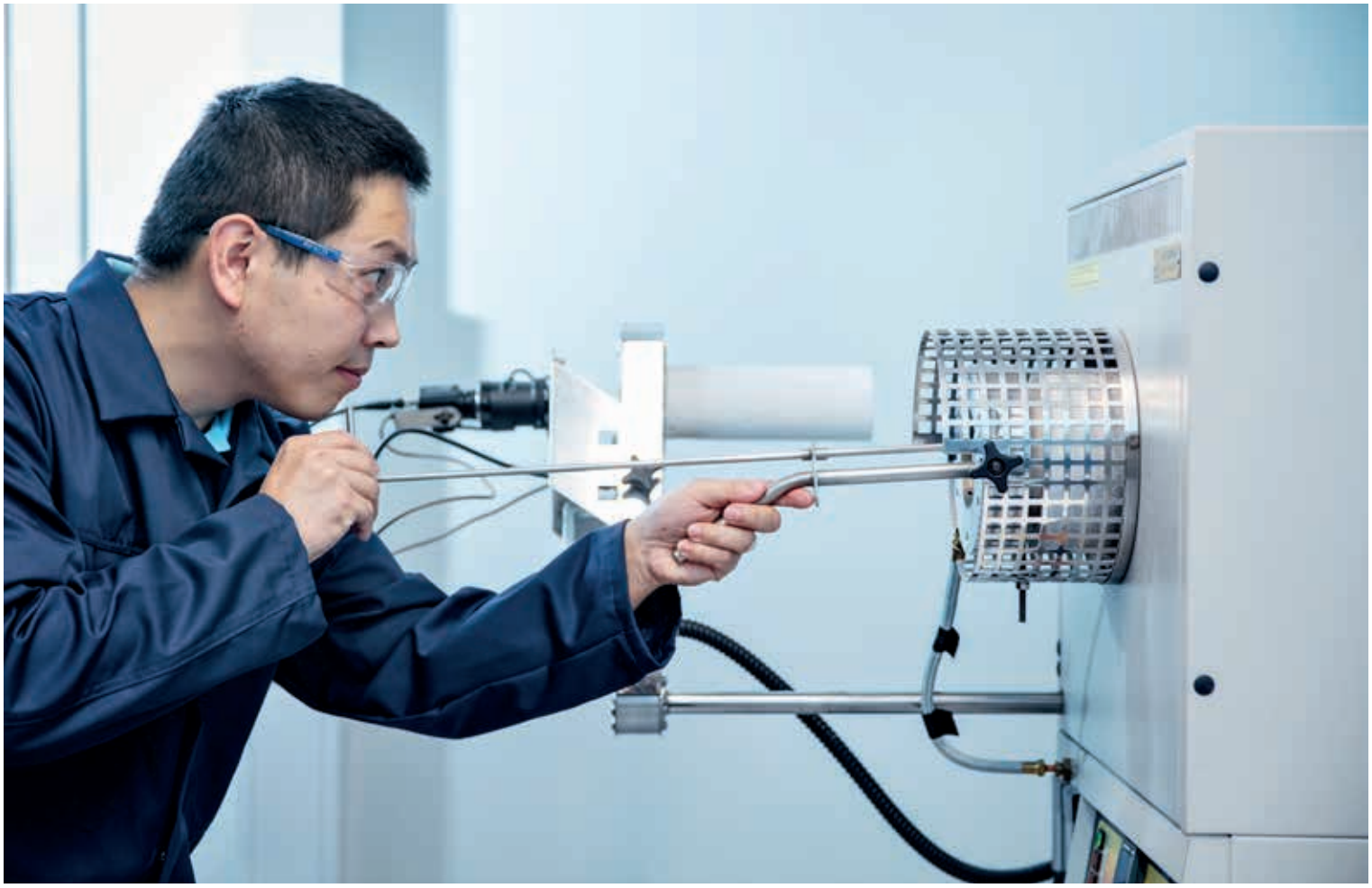
The poster identified many of the unique advantages, challenges and novel aspects of the Waste-to-Energy sector that are discussed elsewhere in this report.

Biomass is also a key feedstock

Biomass-to-Energy is the most important contributor to district heat production after WtE. CenBio was involved in several activities in this sector:

1. Extensive mapping of emissions took place at several full-scale plants: Akershus Energi bioenergy plant in Lillestrøm, Statkraft Varme Marienborg (Trondheim) and Hammergård (Kungsbacka, Sweden) bioenergy plants.
2. Ash research activities focused on ash from biomass combustion:

- In biomass plants, separate collection of fly ash and bottom ash is needed to use ash in fertilizers. Bottom ash will normally have a sufficiently low content of heavy metals



SINTEF research scientist Liang Wang, who started in CenBio as a PhD candidate and then kept on working in the Centre, was key in the studies of ash deposits and deposition mechanisms.

Photo: SINTEF/Geir Mogen.

for use in agriculture or urban greening
- Experiments to use bio-ash as fertiliser and raw material
- Participation in the EU working group STRUBIAS (development of nutrient recovery rules for struvite, biochar and ash based products)
- Ash as an alternative component in raw meal of cement.

3. Heat production from liquid biofuels, a cooperation between NMBU, SINTEF, Hafslund Varme, Akershus Energi and Statkraft Varme to reduce operational challenges and feedstock costs. The liquid biofuel market is unpredictable, and the products vary in quality, accessibility and price. In addition, the peak loads might seldom occur, meaning that the liquid biofuels often will be stored at the district heating plant for long periods. The risk for operating problems due to precipitation and clogging is high.

All our user partners were very positive about the work and the results

How do you solve a problem like ash?

There is a significant environmental challenge with the disposal of ash in landfills and leaching, so researching the possible upgrade of ash into valuable products was a focus area throughout the lifetime of the Centre.

During combustion, ash can cause slagging, deposition, fouling and corrosion, which will have an impact on the operation, overall performance and maintenance costs. After combustion, fly ash & bottom ash from WtE must be disposed and this has a cost up to several hundred Norwegian kroner per ton of ash. The challenge for the industry is turning this expenditure into revenue by upgrading ash into valuable products or by extracting valuable minerals and/or metals.

The studies on ash (both waste and biomass) within CenBio included:

- Novel methods to abate ash slagging on the grate
- Novel methods to fight high temperature Cl-induced corrosion
- Ash deposits and deposition mechanisms from WtE full-scale plants, i.e. EGE Oslo Klemetsrud & Haraldrud plants, Statkraft Varme Heimdal

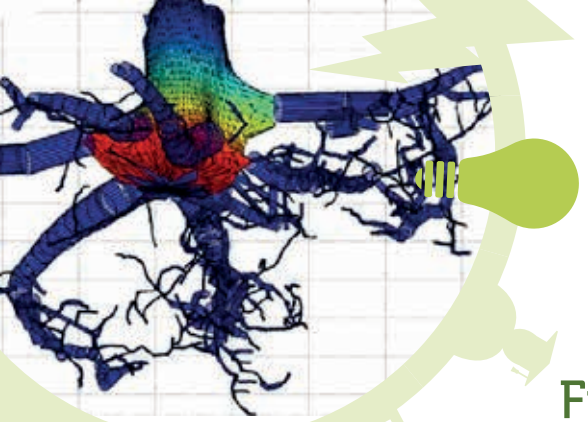
"Samples of ash deposits were analysed with very advanced methods with the aim to understand what happens to the different chemical elements during combustion," explains Becidan. "All our user partners were very positive about the work and the results. Such a study had never been done before at the plants we selected. It increased the general knowledge about this important subject."

Johnny Stuen, Technical Director for the City of Oslo's WtE agency (EGE Oslo), was a key industrial stakeholder in this activity.

"There has certainly been a broad public acceptance of WtE as an industry that society needs, and there is a movement towards more recycling and zero waste. Working towards a society with no waste means we have to work with solutions that need to ensure we can valorise the bottom ash and the fly ash. The most important aspect of CenBio for us has been the ability to work with both researchers and industry to increase knowledge across the value chain," he says.

Chimneys of the Statkraft Varme Waste-to-Energy plant in Heimdal.
Photo: Alexis Sevault.

Johnny Stuen, Technical Director for the City of Oslo's WtE agency (EGE Oslo) at the Klemetsrud Waste-to-Energy plant.
Photo: EGE Oslo.



From ideas to reality

Over the past eight years, CenBio has paved the way towards innovative multi-disciplinary research work within the Norwegian bioenergy sector, bringing a new vision to the developing bioenergy market and highlighting its large potential for growth.

If sustainable bioenergy is to be one of the cornerstones of renewable energy supply when moving to a low carbon society, then technical improvements and innovations must take place in all areas to relieve the pressure on resources. Energy production and storage, use of energy, or use and reuse of biomass, materials and land are all fields ripe for innovation.

Innovation List

Keeping track of and supporting innovations for implementation in industry was a key element of the Centre's work and was the responsibility of SINTEF research scientist Mette Bugge. Four innovation workshops were held in 2010, 2011, 2013 and 2015 to bring focus on the topic and realise the potential within CenBio. The Centre's definition of innovation is wide, incorporating new tools, techniques, methodologies and processes alongside technological breakthroughs.

Throughout the life of CenBio, the Innovation List has documented progress towards the target of 25 completed innovations. More than 35 potential innovations were tracked, and by February 2017, 20 were completed and ready for utilisation. The 20 completed innovations are illustrated on the next page.

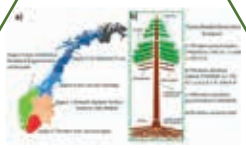
Bioenergy Innovation Award

In 2010 CenBio introduced the Bioenergy Innovation Award (BIA), which has quickly become a nationally recognised innovation award within stationary bioenergy. The award was established to stimulate and reward knowledge-based innovation and entrepreneurship, to identify projects with innovation potential and shine a light on innovative thinking and activities within bioenergy. A six-person committee was established to choose the annual winner, based on a set of criteria including innovative thinking, research-based development and commercial potential. Committee members included representatives from ENOVA, the Research Council of Norway, NoBio, Innovation Norway, as well the CenBio Centre Coordinator and the Deputy Centre Coordinator.

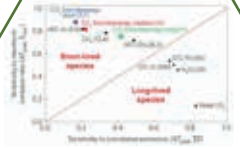
The winner of the first award in **2011** was Edvard Karlsvik of SINTEF Energy Research, for his work with combustion technology for residential wood stoves. Karlsvik had worked with wood stoves for 30 years and was an important person in the development of clean burning wood stoves.

From left: Johan Hustad (NTNU) and Edvard Karlsvik (SINTEF).
Photo: CenBio.

CenBio Innovations



Climate impact of CO_2 emissions from biomass

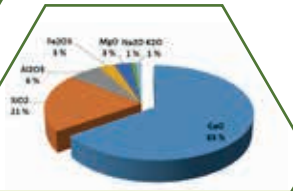


Short-lived vs. long-lived climate forcers

Tool for strategic supply chain in forestry

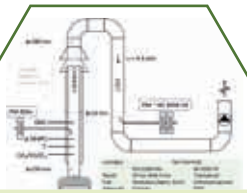
Soil mixture with ash for urban greening

Method for measuring moisture in forest fuel



Bio bottom ash as raw material for Portland Cement

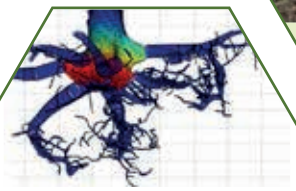
Special sand for prevention of weed germination



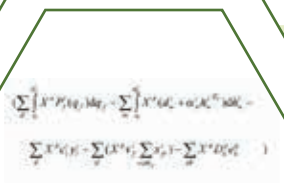
New test method for wood stoves

Recommendations for sustainable harvesting

Contribution to development of international standards



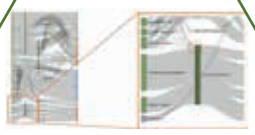
Biomass functions for estimation of birch in Norway



EFI-GTM partial equilibrium model for forest sector

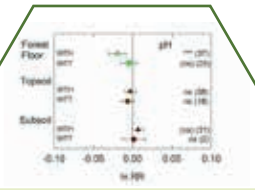
Afterburner for soapstone wood stoves

On-line syngas calorific value measurement



Environmental performance for biomass value chains

Improved grapple for forestry



Criteria and indicators for sustainable bioenergy

Albedo effects and forestry

National forest sector model (NorFor)

Firewood properties calculator

From left: Odd Jarle Skjelhaugen (NMBU), Lars Sørum (SINTEF), Per Lillebø (CEO Cambi), Pål Jahre Nilsen (Research director at Cambi) and Ruth Haug (NMBU).
Photo: Kai Tilley.

In **2012**, CenBio user partner Cambi AS received the award for their biogas production process for biomass from waste and sewage sludge, which is implemented in many plants worldwide.

The **2013** prize went to Solør Bioenergi, the first external winner of the award. Exclusively using contaminated (impregnated) timber as energy source in their 10 MW combined heat and power (CHP) plant, Solør Bioenergi demonstrated that it is possible to establish and operate biomass-based CHP plants in Norway in a cost-effective manner, by recognizing and optimally exploiting synergy effects in the market. The committee felt that Solør Bioenergi set an example for others who want to establish biomass-based CHP plants in Norway.

The Solør Bioenergi CHP plant. This plant processes impregnated wood waste to produce electricity, process steam and district heat.
Photo: SINTEF.

The BIA **2014** was awarded to Mjøsen Skog AS on behalf of the ALLMA group for the development of the first web-based GIS-system in Norway that integrates up-to-date forestry plans with operative logistical functions. At the time of the award, these solutions were already implemented and used in day-to-day operations by the three forest owners' cooperative.

From left: Rune Volla (Research Council of Norway), Berta Matas Güell (SINTEF), Erik A. Dahl (Mjøsen Skog) and Odd Jarle Skjelhaugen (NMBU).
Photo: Alexis Sevault.

In **2015**, Vincent Eijsink from NMBU took the prize for his work within the field of enzyme technology and biogas processes. His scientific research group has an international reputation and are good at linking basic scientific research and industrial interests.

Antec Biogas, a spin-off company from the research community at NMBU and NIBIO, received the **2016** award for their development of a new type of biogas reactor based on plug-flow transport of the biodegradable material through the reactor. The process consists of several chambers mounted in series, enabling the optimisation of the various sub-processes in each separate chamber. In addition, the reactor is a biofilm reactor, which means that the microorganisms can live in the biofilm and will not follow the biomass leaving the reactor.

The committee commented that the company's work represents a possible paradigm shift in the production of biogas, and that the reactor can become a successful Norwegian export commodity that can create new business opportunities in Norway and internationally.

The final award presented during the life of CenBio was awarded at the CenBio Final Conference in March **2017**. The winner was Prediktor Instruments AS. They have developed the Spektron Biomass Analyzer, an instrument based on near-infrared (NIR) technology that is capable of measuring moisture content in forest fuels under variable environmental conditions, including freezing temperatures. The fast, accurate method represents a significant improvement over the standard method which can take up to 24 hours.

The committee commented that this innovation will contribute to the professionalisation of the bioenergy industry and have a major impact on the bioenergy value chain.

Vincent Eijsink (NMBU).
Photo: NMBU.

From left: Marie Bysveen (SINTEF), Trond Værnes (Research Council of Norway), Uno Andersen (Antec Biogas), Egil Andersen (Antec Biogas) and Odd-Jarle Skjelhaugen (NMBU).
Photo: Michaël Becidan/CenBio.

NIR Prediktor Spektron measuring moisture content of wood chips in real time.
Photo: Eirik Nordhagen.

CenBio's impact on bioenergy in Norway

During its eight-year life, the Centre played an important role in developing the bioenergy industry in Norway.

Before CenBio

Prior to CenBio's creation in 2009, both the bioenergy industry and R&D actors were fragmented. The variety of logistics, feedstocks, technologies, applications, products and business models meant structured cooperation was difficult, especially as many of the actors were small or medium-sized companies.

Almost no electricity was produced from biomass or waste as hydropower had such a strong position. Bioenergy supplied about 15% of the space heating in Norway, which is much less than other Scandinavian countries despite the concept of wood stoves being so intrinsically linked with the 'Norwegian spirit'.

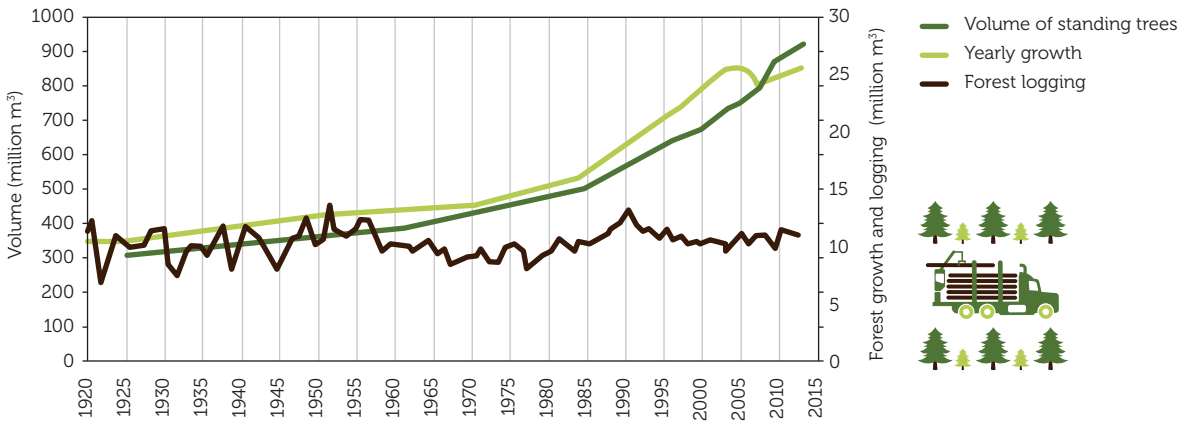
Forest owners controlled most of the biomass resources but only half of the forest growth was utilised every year. In fact, the volume of available Norwegian forest has been growing for almost a century.

Waste-to-Energy evolved within a strict regulatory framework as the backbone of the burgeoning district heating networks, while bioheat plants were mostly small with capacity below 3 MW.

Some industrial sectors (pulp and paper, sawmills) produce several TWhs bioenergy from their biomass by-products/ residues, mainly for internal use.

The decision to tax liquid biofuels the same way as

Forest volume, growth and logging over 1920–2013



Exploitation of the Norwegian forest for the last century.

Source: NIBIO/SSB.

fossil fuels put large industrial biorefinery projects on hold.

Overall, Norway produced 14 TWh of bioenergy, only a fraction of Sweden's 130 TWh, but a national bioenergy plan aimed to double this value by 2020.

CenBio was ready to play its part.

During CenBio

CenBio initiated two nationwide movements: An increased co-operation between the principal R&D sites at Ås and in Trondheim, and a coming together of industry from across the various biomass and waste-based energy value chains.

CenBio's creation of a national team allowed R&D partners to reach a critical mass, leading to an increase in quality, quantity and scope of Norwegian research. This gave a more integrated and structured research agenda and research activities on each segment of the bioenergy value chains.

For industry, hot topics such as operation, emissions and sustainability were tackled. The Centre also took advantage of the eight-year timeline to provide insight into innovative technologies and upcoming solutions yet to be developed.

The increased use of cheaper but more challenging biomass residues while increasing energy efficiency and decreasing emissions has been a trend throughout the life of the Centre. This is needed to avoid competition for pricey virgin biomass but also to utilise untapped resources. This topic will remain a central challenge after CenBio. Another important R&D thread has focused on tailor-made solutions for specific fractions such as food waste, demolition wood and wet biomass.

CenBio researchers have been involved in several important national and international strategic and political initiatives to shape the goals and vision associated with bioenergy and secure Norway's interests. This includes the IPCC (Intergovernmental Panel on Climate Change) reports, Skog22, European Technology Platforms, EERA (European Energy Research Alliance) Bioenergy, IEA (International Energy Agency) tasks and EU standardisation work. This has placed partners at the forefront of new technology and trend development (also when it comes to policies), and placed Norway firmly on the bioenergy map.

CenBio's multifaceted contribution includes knowledge exchange between industry and R&D through activities at partner plants, technical workshops and dissemination of research. Common bioenergy courses between NMBU and NTNU along with high numbers of PhD candidates and Master students, and the high number of spin-off research projects have helped ensure a bright future for bioenergy research and development in Norway.

New actors from other sectors are now showing interest or even entering the biomass and bioenergy markets

Technical contributions on specific elements in the bioenergy value chains have included:

- Improved mapping of forest resources
- Optimisation of logistics
- Waste characterisation, new fractions utilisation and the ash challenge
- Emissions mapping and modelling of processes in CHP plants
- New feedstocks and improved biogas production
- Cleaner and more efficient wood stoves

Bioenergy in Norway today

Norwegian bioenergy research and development is globally relevant, and many partners are involved in large international projects. The quality and quantity of peer-reviewed scientific publications have increased greatly and several R&D groups have strengthened their position and have now top competence at the international level. Examples of this are NTNU with life cycle analysis, SINTEF with wood stoves, and NIBIO with biogas. The R&D laboratory and modelling infrastructures are strengthened thanks to CenBio initiatives and the support of the Research Council of Norway.

Most of the industrial actors are still small. Bioenergy from virgin biomass is marginally profitable as energy prices have dropped during the life of the Centre,

mainly because of the dominance of affordable hydropower.

Waste-to-Energy capacity has increased (from 1 Mt/year to about 1.7 Mt/year) in parallel with the development of district heat networks, but there is now little room for new large projects. Gate fees are still under threat from Swedish plants.

The situation elsewhere in industry is diverse:

- The amount of forest biomass harvested is stable, and the forest is still growing
- Wood stoves are still the main bioenergy contributor
- Biogas has received great interest but few large installations are in operation in Norway
- Almost 1,000 bioenergy plants are now in operation but very few are above 5 MW
- There is still no significant market for wood pellets in Norway
- Green electricity certificates have not led to many new bio-electricity projects in Norway
- Several large Norwegian paper producers have disappeared or dramatically reduced their output, which means forest owners have had to look abroad
- More stringent regulations, especially concerning emissions from combustion plants, have been introduced

The number of bioenergy projects has increased significantly, which illustrates the closer relationship between R&D and industry. At the same time, new actors from other sectors are now showing interest or even entering the biomass and bioenergy markets. Furthermore, emerging industrial initiatives may soon make an impact, including biorefineries, liquid biofuel and biocarbon projects.

CenBio has accompanied the development of bioenergy in Norway for almost a decade, sharing its successes but also its challenges. The ties and knowledge born of CenBio shall live on and cooperation continue for many years to come.

SINTEF research scientists in the CenBio Management Team.
From left: Einar Jordanger, Michaël Becidan, Øyvind Skreiberg and Alexis Sevault.
Photo: SINTEF/Gry Karin Stimo.

Beyond CenBio

The Centre's work may be at an end, but its legacy lives on with further cooperation, new projects, and new opportunities to advance the Norwegian bioenergy industry.

There is little doubt that the CenBio method of intense contact and cooperation between most major Norwegian bioenergy actors will be long lasting. But is it enough to meet the threats, challenges and opportunities ahead?

It seems that the current goal of 28 TWh stationary bioenergy by 2020 is not realistic by sticking to business as usual. The annual increase since 2009 has been below 1 TWh to reach the current amount of 18-19 TWh. The reason is a complex mix of low profitability, the public debate on the sustainability of bioenergy, the lack of a clear vision on what to do with Norwegian biomass, the strong position of hydropower and at times low energy prices.

But the signs are there for a bright future. A circular economy and the transition towards a green, renewable society in Europe cannot be achieved without including biomass and waste. Bioenergy should continue its transition towards improving its overall efficiency and economic and environmental performance, also using a variety of low quality and affordable biomass fuels.

Furthermore, many fields remain open to new research such as knowledge and processing technologies within forest-based biofuels for heavy transport and aviation. Bio-based materials and high-value chemicals are of high interest to strengthen biofuel production profitability. Untapped feedstocks, such as aquatic resources, must be included in the production chains.

NMBU Rector Mari Sundli Tveit at FME Bio4Fuels' kickoff meeting.
Photo: Håkon Sparre.

Spin-off projects

One of the most visible legacies of CenBio is the high number of spin-off projects that were initiated based on research findings within the Centre. About 100 project proposals (both national and European) were created and half were successfully funded, an impressive success rate.

Bio4Clim (2015-2018, operated by NTNU and NIBIO) is a research project designed to gain insights into the design of future climate-effective resource supply and utilization strategies and policies both for Norway and the broader Fennoscandia region. The project will contribute new empirical models for predicting future trends, contribute to additional knowledge surrounding the climate physics of biogenic volatile organic compounds, and advance methods for integrating land management changes into climate models.

The aim of **BioCarb+** (2014-2017, led by SINTEF and with NIBIO, NTNU and the University of Hawaii as research partners) is to develop new strategies for the use of low-grade biomass, pulpwood and energy wood resources to produce biocarbon (also known as charcoal) for use in industry and conversion to energy. The goal is to reduce harvesting and logistics costs, maximise charcoal yield and quality produced by carbonisation, and maximise energy efficiency and reduce emissions in end-use applications.

"Most charcoal bought in stores has been produced in developing countries, and may well have been produced using inefficient processes with high emissions. An interesting question is whether we can improve the production process and yields to the point where it is economically viable to produce biocarbon from Norwegian resources," says Øyvind Skreiberg, Chief Scientist from SINTEF Energy Research.

NMBU and NIBIO research scientists in the CenBio Management Team. From left: Simen Gjølsjø, Odd Jarle Skjelhaugen and Per Kristian Rørstad. Photo: Erling Fløistad.

A new direction with a new FME Centre

Hosted by NMBU and led by SINTEF, Bio4Fuels - the Norwegian Centre for Sustainable Bio-based Fuels and Energy – kicked off in February 2017.

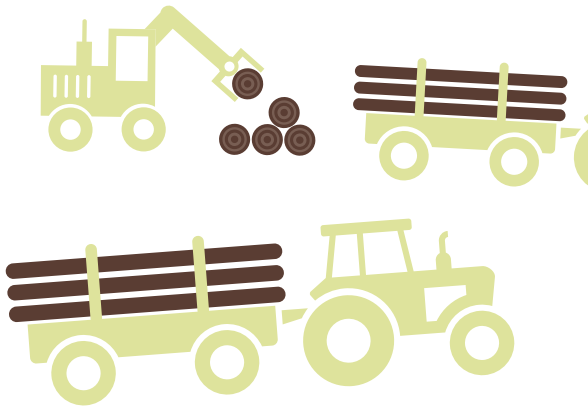
The new Centre will develop technologies for second-generation biofuels

The new Centre will develop technologies for second-generation biofuels and among its objectives is to achieve as much as a 30% reduction in production costs compared to current cost levels. Biofuels may represent a vital contribution to cutting CO_2 emissions in the transport sector.

Bio4Fuels is one of eight new Centres for Environment-friendly Energy Research (FME). The Research Council of Norway, the user partners and the research partners have guaranteed an annual allocation of about NOK 30 million for up to eight years.

Learning from CenBio should have a positive impact on the ability of Bio4Fuels to make a quick start. "A range of technologies exists for converting biomass into fuels, heat and power. To develop second generation biofuels and energy viable for commercial production, cross-sectional knowledge and efforts must be united," says CenBio Deputy Centre Coordinator Odd Jarle Skjelhaugen.

"It took several years to build the multidisciplinary teams with the right people and the right routines to help make CenBio a success for all participants. This is learning we will take forward into Bio4Fuels," he adds.



CenBio
Bioenergy Innovation Centre

Basic facts about the Centre

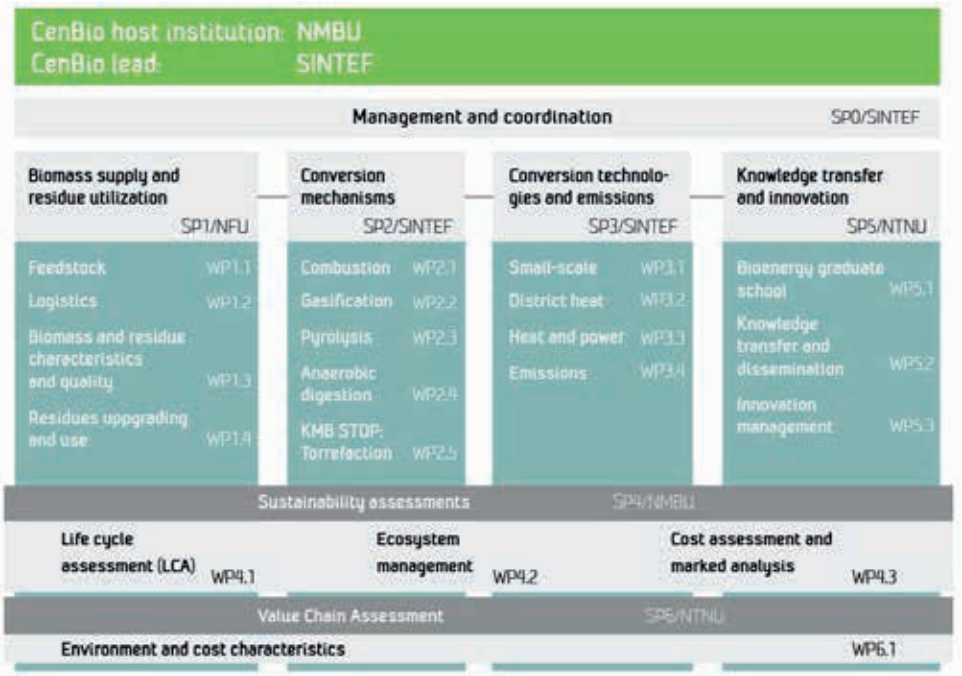
CenBio - the Bioenergy Innovation Centre - was one of the Norwegian Centres for Environment-friendly Energy Research *(in Norwegian: FME - Forskningssentre for miljøvennlig energi)*. The Centre was co-funded by the Research Council of Norway, a number of user partners and the participating research institutions.

NMBU - Norges miljø- og biovitenskapelige universitet *(Norwegian University of Life Sciences)* was the host institution, and SINTEF Energi AS *(SINTEF Energy Research)* was the coordinating institution.

Partners

CenBio started in 2009 with 7 R&D partners and 19 user partners.

- **R&D partners:** NMBU - Norwegian University of Life Sciences, SINTEF Energy Research, NTNU – Norwegian University of Science and Technology, NIBIO – Norwegian Institute of Bioeconomy Research, SINTEF Materials and Chemistry, Vattenfall Research and Development AB.
- **User partners throughout the Centre lifetime:** Akershus Energi AS, Norges Skogeierforbund (Norwegian Forest Owners' Federation), Hafslund Varme AS, Statkraft Varme AS, Oslo Kommune Energigjenvinningsetaten, Vattenfall AB Nordic Heat, Energos AS, Cambi AS, Jøtul AS, Norsk Kleber AS.
- **User partners for part of the Centre lifetime:** Agder Energi AS, NTE Holding AS, Norske Skogindustrier ASA, Xynergo AS, Norsk Protein AS, Avfall Norge, Norges Bondelag, Afval Energie Bedrijf b.v., Bionordic AS.



Main organisation of the Centre

The technical activities within CenBio were organised into six sub-projects (SP), each divided into Work Packages (WP), as shown on previous page. Note that SP6, the Value Chain Assessment, started from January 2013.

Executive Board

The Executive Board (EB) of CenBio consisted of 7 members: 4 members elected by the user partners and 3 members from R&D partners. The Research Council of Norway was also present as observer. Most of the 27 EB meetings were arranged as in-person events, often in conjunction with other CenBio meetings.

As of January 2017, the Executive Board consisted of:

Role	Name	Affiliation
Chairperson	**Petter Røkke**	SINTEF Energi AS
Members representing R&D partners	**Olav Bolland**	NTNU
	Ragnhild Solheim	NMBU
Members representing user partners	**Eilif Due**	Norges Skogeierforbund
	Morten Fossum	Statkraft Varme AS
	Johnny Stuen	EGE – Oslo kommune
	Pål Jahre Nilsen	Cambi AS

Scientific Advisors

Scientific Advisors were appointed in 2010, one for each scientific SP.

The Scientific Advisors have all been international experts who provided advice on the relevance and quality of the scientific activities, trends, challenges and opportunities in a national and global context, and scientific partnerships.

Advisory Board

The Advisory Board was established in 2014 after recommendations from the mid-term evaluation arranged by the Research Council of Norway. The main purpose of the external Advisory Board was to provide unbiased advice to the EB about the relevance and quality of the activities planned and performed by CenBio, as well as guidelines for future bioenergy research needs post-CenBio.

Scientific Advisors

SP	Name	Affiliation
SP1	**Heikki Pajuoja**	Dir. Metsäteho Oy
SP2	**Mikko Hupa**	Prof. Åbo Akademi University
SP3	**Michael J. Antal, Jr.**	Prof. University of Hawaii
SP4	**Pekka Kauppi**	Prof. University of Helsinki

Advisory Board

Name	Affiliation	Country
Pat Howes	Ricardo	UK
Arto Timperi	Comatec	Finland
Claes Tullin	RISE (former SP)	Sweden
Marcel van Berlo	Technology & Strategy BV	Netherlands

Key researchers

Many bioenergy researchers were actively involved throughout the duration of CenBio. Only the key researchers most involved in the Centre are listed in the table below. Lars Sørum (SINTEF) and Berta Matas Güell (SINTEF) also acted as Centre coordinators earlier in the Centre lifetime.

Key researchers

Position or sub-project	Name	Affiliation
Centre Coordinator	**Marie Bysveen**	SINTEF
Deputy Centre Coordinator	**Odd Jarle Skjelhaugen**	NMBU
Centre Manager	**Einar Jordanger**	SINTEF
Centre Management and Organising Committee	**Alexis Sevault, Line Rydså**	SINTEF
SP1 Biomass Supply and Residue Utilization – Leader: **Simen Gjølsjø** (NIBIO)		
WP1.1 – Feedstock Supply – Leader: **Tron Haakon Eid** (NMBU)		
WP1.2 – Logistics – Leader: **Bruce Talbot** (NIBIO)		
WP1.3 – Biomass and Residue Characteristics and Quality – Leader: **Judit Sandquist** (SINTEF)		
WP1.4 – Residue Upgrading and Use – Leader: **Trond K. Haraldsen** (NIBIO)		
Even Bergseng (NMBU), **Liang Wang** (SINTEF), **Eva Brod** (NIBIO), **Tormod Briseid** (NIBIO), **Helmer Belbo** (NIBIO), **Eirik Nordhagen** (NIBIO), **Nils Egil Søvde** (NIBIO), **Janka Dibdiakova** (NIBIO), **Bjarte Øye** (SINTEF)		
SP2 Conversion Mechanisms – Leader: **Michaël Becidan** (SINTEF)		
WP2.1 – Combustion – Leader: **Øyvind Skreiberg** (SINTEF)		
WP2.2 – Gasification – Leader: **Michaël Becidan** (SINTEF)		
WP2.3 – Pyrolysis – Leader: **Khanh-Quang Tran** (NTNU)		
WP2.4 – Anaerobic Digestion – Leader: **Tormod Briseid** (NIBIO)		
WP2.5 – KMB STOP – Leader: **Øyvind Skreiberg** (SINTEF)		
Svein Jarle Horn (NMBU), **Vincent Eijsink** (NMBU), **Roger Khalil** (SINTEF), **Liang Wang** (SINTEF), **Tian Li** (NTNU), **Roar Linjordet** (NIBIO), **Roald Sørheim** (NIBIO)		
SP3 Conversion Technologies and Emissions - Leader: **Øyvind Skreiberg** (SINTEF)		
WP3.1 – Wood / Pellets Stoves – Leader: **Morten Seljeskog** (SINTEF)		
WP3.2 – District Heat – Leader: **Michaël Becidan** (SINTEF)		
WP3.3 – Heat and Power – Leader: **Øyvind Skreiberg** (SINTEF)		
WP3.4 – Emissions – Leader: **Mette Bugge** (SINTEF)		
Franziska Goile (SINTEF), **Åsa Astervik** (Vattenfall), **Håkan Kassman** (Vattenfall), **Matthias Mattsson** (Vattenfall), **Christer Forsberg** (Vattenfall)		
SP4 Sustainability Analysis – Leader: **Birger Solberg / Per Kristian Rørstad** (NMBU)		
WP4.1 – Life Cycle Assessment (LCA) – Leader: **Francesco Cherubini** (NTNU)		
WP4.2 – Ecosystem Management – Leader: **Nicholas Clarke** (NIBIO)		
WP4.3 – Cost Assessment and Market Analysis – Leader: **Birger Solberg** (NMBU)		
Alexander Moiseyev (NMBU), **Geoffrey Guest** (NTNU), **Sajith Vezhapparambu** (NTNU)		

SP5 Knowledge Transfer and Innovation – Leader: **Terese Løvås** (NTNU)
WP5.1 – Bioenergy Graduate School – Leader: **Terese Løvås** (NTNU)
WP5.2 – Knowledge Transfer and Dissemination – Leader: **Odd Jarle Skjelhaugen** (NMBU)
WP5.3 – Innovation Management – Leader: **Mette Bugge** (SINTEF)
Berta Matas Güell (SINTEF), **Line Rydså** (SINTEF), **Alexis Sevault** (SINTEF)

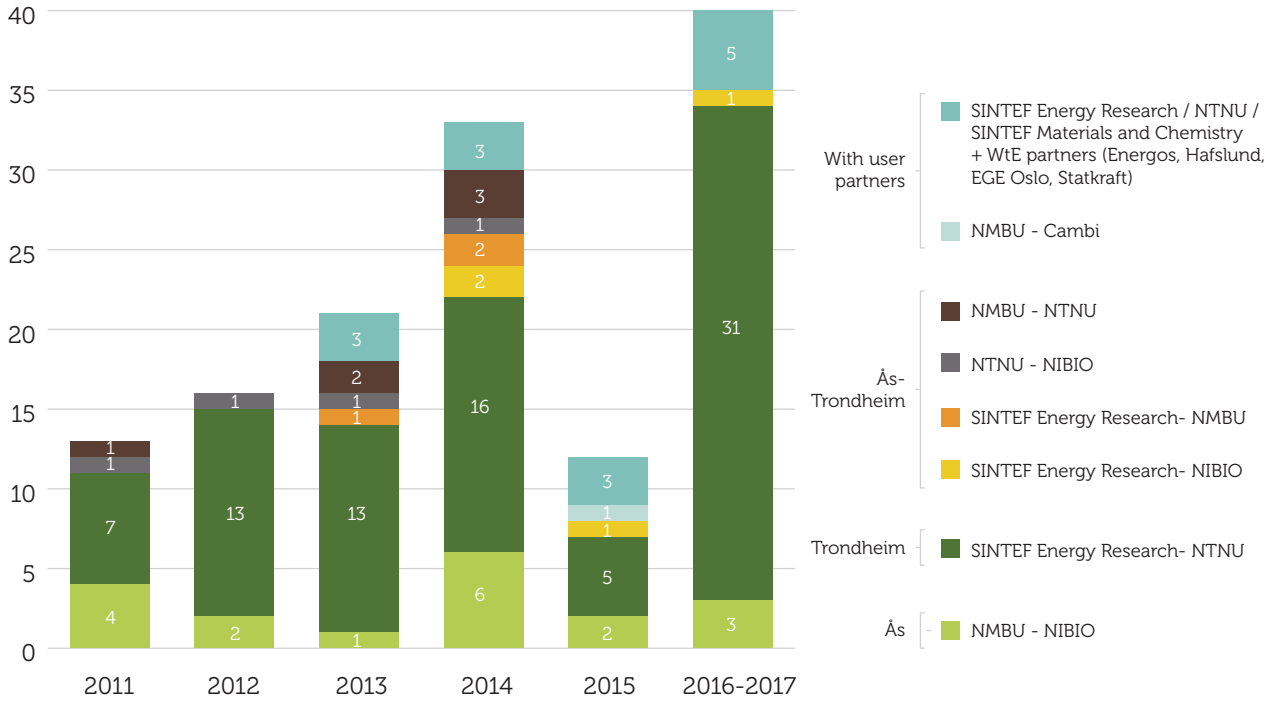
SP6 Value Chain Assessment – Leader: **Francesco Cherubini** (NTNU)
Anders H. Strømman (NTNU), **Per Kristian Rørstad** (NMBU), **Gonzalo del Alamo Serrano** (SINTEF), **Carine Lausselet** (NTNU), **Anders Arvesen** (NTNU), **Michaël Becidan** (SINTEF), **Tormod Briseid** (NIBIO), **Helmer Belbo** (NIBIO), **Bruce Talbot** (NIBIO), **Øyvind Skreiberg** (SINTEF), **Morten Seljeskog** (SINTEF), **Franziska Goile** (SINTEF)

Cooperation within the Centre

The research activities in CenBio were mainly performed at universities and research institutes at Ås and in Trondheim. One R&D partner, Vattenfall R&D based in Sweden, worked in close cooperation with SINTEF Energy Research. Internal collaboration was especially important within SP6 Value Chain Assessment and other sub-projects in CenBio.

The total number of internal collaborations leading to peer-reviewed publications (both journal and conference) was 135, with details shown in the figure below.

Internal collaborations leading to peer-reviewed publications
(per February 2017, total number: 135)



Organising committee and yearly project meetings

Each year, the Centre invited all partners to attend the CenBio Days, in conjunction with the General Assembly. The programme typically included presentations from selected CenBio researchers and user partner representatives, as well as invited external speakers. Since 2013, a second yearly meeting was organised with all the partners focusing on the upcoming year's activities. Researchers and industry representatives could discuss how to prioritise research activities and contribute to the user partners' targets. Programmes often included visits to research or industrial facilities.

Both types of events were coordinated by the organising committee. It involved representatives from user partners and R&D partners as well as the Centre management, and its task was to establish the best possible programme taking into account the opinion of the various stakeholders within CenBio. The committee was led by SINTEF research scientist Alexis Sevault and the most active partner representatives were Hans Olav Midtbust, Erik A. Dahl, Eilif Due, Arne Bardalen, Øystein Johnsen and from the CenBio management team Odd Jarle Skjelhaugen, Michaël Becidan and Simen Gjølsjø.

Financing through the life of the Centre

Summary of the main financial contributions by category of partners:

Contributor	Cash (kNOK)	In-kind (kNOK)	Total (kNOK)
User partner - Resource owner	11 050	4 784	15 834
User partner - Technology providers	3 000	15 214	18 214
User partner - Energy and others	13 750	16 255	30 005
Research partners	0	79 011	79 011
Research Council of Norway	120 000	0	120 000
Sum	147 800	115 264	263 064

Where do we go from here?

Bioenergy is the most important renewable energy asset in Europe so without doubt, there is a strong need to continue the work of CenBio both from a Norwegian and a European perspective. The European Council has set a target that at least 27% of energy consumed across the EU by 2030 should be from renewable sources.

Optimal use of our biomass resources and continued technology development is crucial to reach this target.

Biomass for heat and power is largely local and based on side-streams from the forest industry, and should be developed further. In Norway, the inclusion of marine biomass into the energy system will be an important step forward.

There is also a clear need for greater synergies between the circular economy and biomass uses. This includes further optimisation around the roles of biomass for fuel, energy and chemicals, respectively.

Waste-to-Energy is becoming increasingly important, especially when considered together with CO_2 capture and storage (CCS), while biogas will play important roles in the future energy system and waste handling eco-system.

Last but not least, CenBio stakeholders are keen to see further industrial development and blooming innovations as a result of this FME.

www.CenBio.no

Host institution

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Coordinating institution

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www.CenBio.no

The scheme of the Centres for Environment-friendly Energy Research (FME) seeks to develop expertise and promote innovation through focus on long-term research in selected areas of environment-friendly energy, transport and CO_2 management in close cooperation between prominent research communities and users.

CenBio

Bioenergy Innovation Centre

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

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