Annual Report 2014

# CenBio

## Bioenergy Innovation Centre

fme
CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Enabling sustainable and cost-efficient bioenergy industry in Norway

# Why we need research on stationary bioenergy

To counter the effects of climate change, the global average temperature must not rise beyond two degrees compared to pre-industrial times. Yet, the world's energy consumption is expected to increase by more than 50 % between 2010 and 2040.

Bioenergy is expected to play a big role in our energy future according to the United Nation's Intergovernmental Panel on Climate Change: "Bioenergy's share of total regional electricity and liquid fuels is projected to be up to 35 and 75 percent, respectively, by 2050". *

Enhanced use of renewable energy, such as bioenergy, is a part of the climate solution. Bioenergy relies on biomass, consisting of any organic material which has stored sunlight in the form of chemical energy. The ultimate goal of stationary bioenergy is to convert this energy into heat and/or electricity in the most sustainable way.

In FME CenBio, researchers address the entire value chains of virgin biomass and biodegradable waste fractions, including production, harvesting and transportation, conversion to heat and power, and upgrading residues to valuable products. In FME CenBio, this work is done in close collaboration with the major Norwegian actors in bioenergy research and industry. As a result, society will be supplied with more renewable and $CO_2$-cutting energy.

We need research and innovation to enable sustainable and cost-effective bioenergy. This is CenBio's main objective.

* mitigation2014.org/

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

CenBio Bioenergy Innovation Centre www.CenBio.no

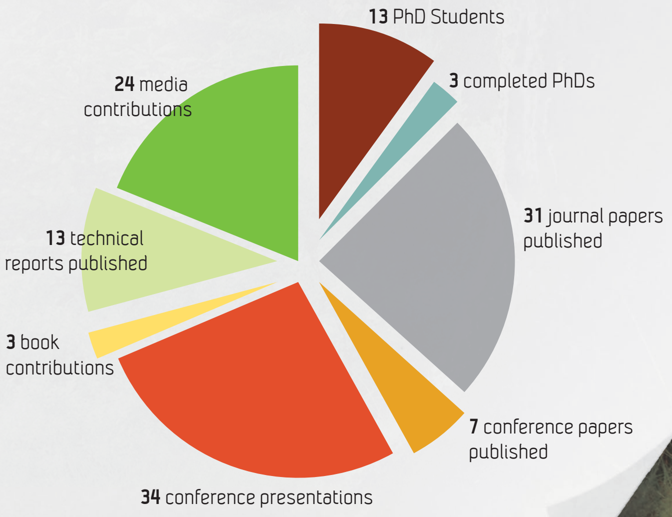
# CenBio

Bioenergy Innovation Centre

## 2014 in numbers

INNOVATIONS

- 9 implemented by 2014
- 23 potential in progress
- 4 about to be finalized



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# Annual Report 2014

Enabling sustainable and cost-efficient bioenergy industry in Norway

## Contents



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

**NMBU – Norwegian University of Life Sciences***(Norwegian University of Life Sciences)* is the host institution, and **SINTEF Energy Research** *(SINTEF Energy Research)* is the coordinating institution.

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Editorial staff at SINTEF Energi (SINTEF Energy Research): Alexis Sevault, Einar Jordanger

# Editorial

**Berta Matas Güell**
***Centre Coordinator***

SINTEF Energy Research

**Odd Jarle Skjelhaugen**
***Deputy Centre Coordinator***

NMBU – Norwegian University of Life Sciences

## 2014 – Successful implementation of the midterm evaluation measures

During 2014, we implemented all the measures defined in the 2013 midterm evaluation. The Research Council of Norway and our User partners have recognized the changes, leading to stronger internal collaboration and tighter involvement of the User partners. Looking at the Centre's key performance indicators, we see a high scientific production and an increasing value for our User partners, corroborating the important role of CenBio as the national bioenergy research platform in Norway.

We would like to underline the active role of our User partners. By mutual understanding, it is possible to meet the practical industrial needs by combining fundamental and applied research. In 2014, the industry's involvement has been concentrated mainly on:

- Prioritizing the planned research activities (Annual Work Plan 2015)
- Assessing a number of detailed value chains (CenBio SP6)
- Co-authorship in scientific publications with our researchers
- Describing bioenergy future scenarios (Foresight Process)

Another element to highlight in 2014 is the Foresight Process that CenBio facilitated. The participants had to think out of the box to describe four distinctive futures for bioenergy in Norway and find the plausible reasons for each of the future situations to happen. The process generated innumerable and fruitful discussions. The foresight report represents a political and commercial strategic decision-making tool.

Furthermore, the number of joint publications between the two distant campuses in Trondheim and Ås is increasing.  Out of the fourteen co-authored publications produced during CenBio's lifetime, eleven were published the last two years (see Figure 5). This collaboration strengthens the link between the two research communities in particular and the national bioenergy sector in general.

*Looking at the Centre's key performance indicators, we see a high scientific production and an increasing value for our user partners*

# Vision and goal

To enable sustainable and cost-efficient bioenergy industry in Norway

CenBio addresses the entire value chains of virgin biomass and biodegradable waste fractions, including their production, harvesting and transportation, the conversion to heat and power, and the upgrade of residues to valuable products. CenBio researchers develop effective, environmentally sound ways of utilizing more biomass and waste for energy purposes. Educating and training the next generation of bioenergy researchers and industry players are essential to attain these ambitious goals.

As a result, consumers and society will be supplied with more renewable and low-carbon energy. By further developing the Norwegian bioenergy industry, a substantial number of new jobs, especially in rural districts, will be created.

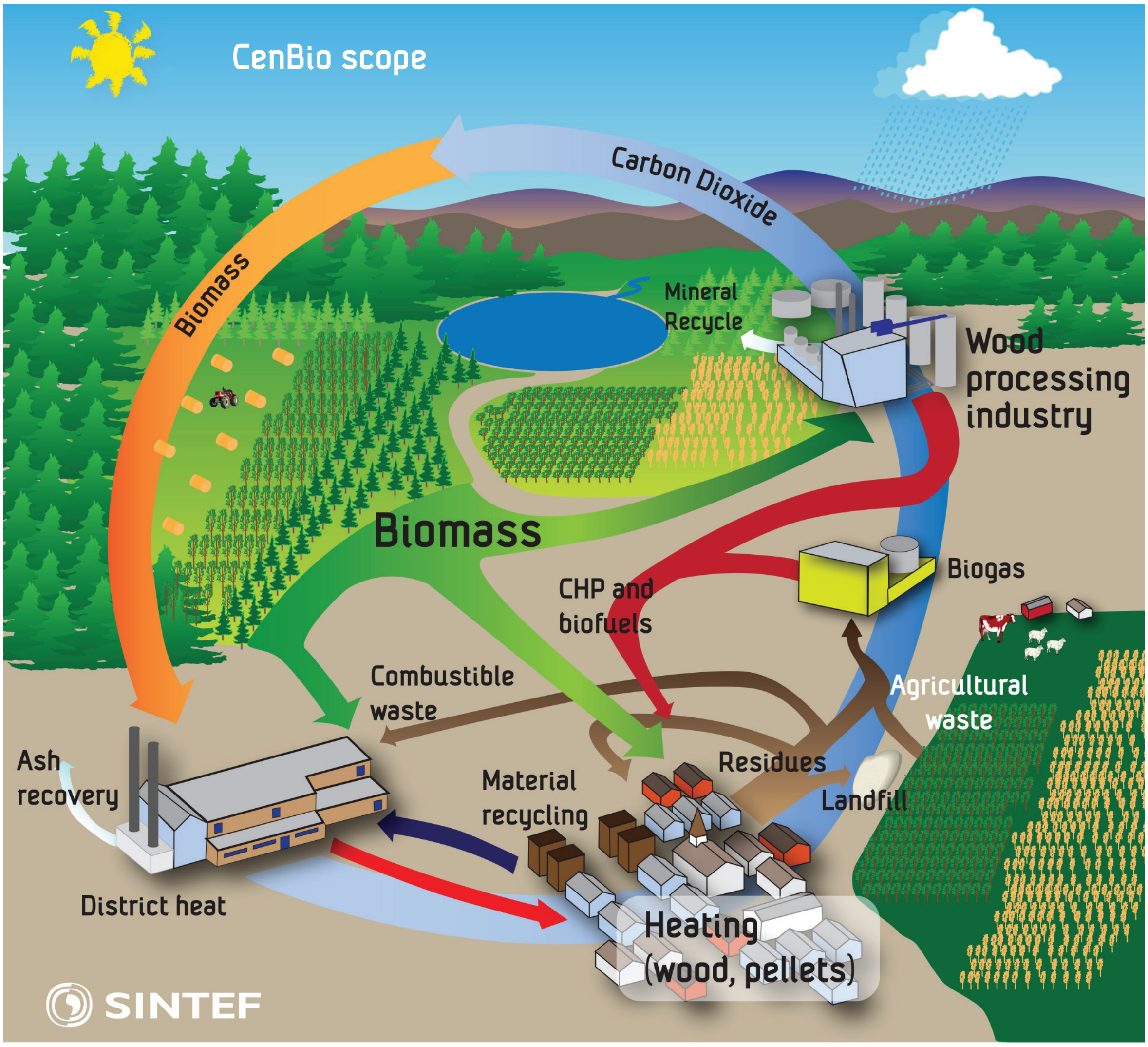


*Figure 1: CenBio Scope*

# Research plan

## CenBio description

The overall objectives and principal work plan are explained in the Centre description prepared during the application phase. The original description is referred to in the R&D Agreement between the Research Council of Norway (RCN) and the host institution NMBU. A new version of the description was submitted in November 2012, as requested by RCN. More detailed plan for the shorter term research activities is required, and an Annual Work Plan is to be submitted for RCN approval at the latest by 31 December each year. The Annual Work Plans will have to be based on the initial and less decisive description, but the course of the research may have to be changed due to external conditions.

## Annual Work Plan 2015

The Annual Work Plan (AWP) 2015 was delivered to the RCN on 31 December 2014. The redaction of the document started at the SP level in September/October 2014, involving meetings with individual User partners to seek for the most relevant research topics. On 29–30 October 2014, a strategic meeting (CenBio Strategic Days) was organized to gather all CenBio researchers and User partners in order to discuss the various topics of interest for 2015 and beyond. This provided a strong basis for the redaction of the full document, which was first improved internally by the researchers and User partners, and then approved by the Executive Board (EB).

## Joint laboratories

CenBio conducts most of its experiments in four dedicated laboratories, partly funded by RCN. The laboratories are:

- Lab. 1: *Biochemical conversion* laboratory (Ås)
- Lab. 2: *Biogas* laboratory (Ås)
- Lab. 3: *Thermochemical conversion* laboratory (Trondheim)
- Lab. 4: *Forest biomass* laboratory (Ås)

Biochemical conversion lab

Biogas lab

Torrefaction unit in Trondheim

*Figure 2: Joint laboratories.* *Photos: NMBU and SINTEF*

# Organisation and coordination

**Einar Jordanger**
***Centre Manager***

SINTEF Energy Research

After the Midterm evaluation process of CenBio in 2013, the evaluation panel and the Research *Council of Norway* (RCN) concluded with some recommendations for improvements of CenBio. Based on these recommendations, the *Centre Management Team* (CMT) proposed a set of detailed actions to be followed up. This action list was approved by the *Executive Board* (EB) and endorsed by the RCN toward the end of 2013. Some of the actions are defined as continuous until the termination of CenBio while others have concrete deadlines. The main axis of these improvements is to **induce stronger interactions** with both the User partners and the international research community and to **enhance the industrial utilization of the research work** performed within CenBio.

The implementation of the detailed actions list started late 2013, as stated in the Annual Report 2013, and has continued during 2014. Some of the actions with major impact on the coordination of CenBio can be summarised as follows:

– The traditional CenBio Days (arranged in March 2014) were extended from two to three days. The *Organising Team* (OT) consisting of representatives from both the research institutions and the User partners, of which two from EB, were actively involved in the preparation of the CenBio Days. The OT ended up with an excellent programme with more involvement from User partners than in previous years. Altogether 62 participants expressed their satisfaction: *"Best CenBio Days ever!"*.

– The **Foresight process** was also a result of the Midterm evaluation. CenBio, as the other FMEs, was challenged to think about future needs for continued research within its respective research area. Three workshops, arranged in January, March and May, resulted in the description of four distinctive future scenarios, all included in the report that was finalised in September. In total, 36 people participated in this exciting process. The main outcomes will be presented to relevant actors in 2015.

– The new **Advisory Board** (AB) recommended by the evaluation panel was established during 2014. Four international experts proposed by EB members have positively accepted their involvement in the Centre. The AB's main purpose is 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. It is worth mentioning that the existing Scientific Advisors will continue their cooperation within the relevant Sub-Projects, in close dialogue with the respective SP Leaders.

– The successful first **CenBio Strategic Day** in 2013 was followed up in October 2014 with a similar format as in 2013. The main objective was to discuss the proposed activities for 2015, and agree the prioritisation of them, in close cooperation with the User partners. Further, the Foresight process and preliminary results from the cross-cutting activity *Sub-Project 6 Value Chain Assessment* were presented. The latter was explicitly acknowledged by the User partners. This CenBio strategic event gathered 44 participants, mostly representing CenBio partners.

## Partners

Initially, 26 partners took part in CenBio. Norwegian University of Life Sciences (NMBU) is host institution and SINTEF Energy Research is coordinating institution. The governance structure is further detailed in Figure 3. Three partners left the Centre in 2011 (Xynergo AS, Afval Energie Bedrijft and BioNordic AS), four in 2013 (Agder Energi AS, Avfall Norge, Norske Skogindustrier ASA and Norges Bondelag) and two in 2014 (Nord-Trøndelag Elektrisitetsverk (NTE) Holding AS and Norsk Protein AS).

The R&D Agreement between the Research Council of Norway (RCN) and the host institution refers to two main categories of partners: Research partners and User partners.

### Research partners

- NMBU, Norwegian University of Life Sciences *(Host institution)*
- SINTEF Energy Research *(Coordinating institution)*
- NTNU, Norwegian University of Science and Technology
- Bioforsk
- Norwegian Forest and Landscape Institute
- SINTEF Foundation (Materials and Chemistry)
- Vattenfall Research and Development AB (Sweden)

### User partners

*(cf. Table 26 for a list of short names)*

- Akershus Energi AS
- Norges Skogeierforbund
- Hafslund ASA
- Statkraft Varme AS
- Oslo Kommune Energigjenvinningsetaten (EGE)
- Vattenfall AB, Heat Nordic (Sweden)
- Energos AS
- Cambi AS
- Jøtul AS
- Norsk Kleber AS

## Governance Structure

The governance structure of CenBio (2014), as defined in the Consortium Agreement is shown in Figure 3.

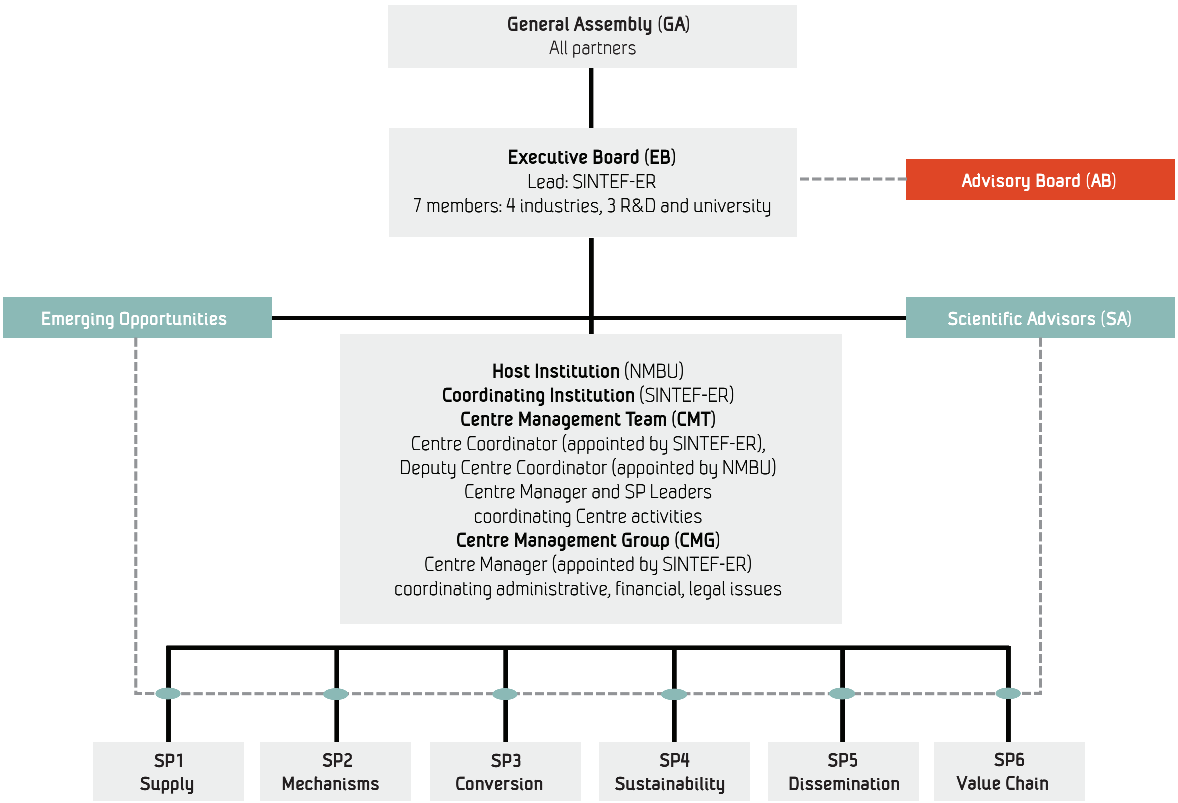


*Figure 3: CenBio Governance Structure. SP stands for Sub-Project.*

**The Executive Board (EB)** consists of seven members, three representing the Research partners and four from the User partners. The Coordinating organisation (i.e. SINTEF-ER) appoints the chairperson.

Table 1: Executive Board members, 2014.

| Position | Name | Affiliation |
|---|---|---|
| Chairperson | **Petter Røkke** | SINTEF-ER |
| EB Member (Research partner) | **Olav Bolland** | NTNU |
| « | **Øystein Johnsen** | NMBU |
| EB Member (User partner) | **Erik A. Dahl** | SKOGEIER |
| « | **Morten Fossum** | STATKRAFT |
| « | **Hans Olav Midtbust** | ENERGOS |
| « | **Pål Jahre Nilsen** | CAMBI |

**The General Assembly (GA)** consists of one representative from all partners, and meets physically at least once a year (usually during the CenBio Days). The list of GA members can be found in Table 2.

Table 2: General Assembly members, 2014.

| Position | Name | Affiliation |
|---|---|---|
| Chairperson | **Gudbrand Kvaal** | SKOGEIER |
| GA Member (Research partner) | **Ragnhild Solheim** | NMBU |
| « | **Petter E. Røkke** | SINTEF-ER |
| « | **Olav Bolland** | NTNU |
| « | **Olav Arne Bævre** | BIOFORSK |
| « | **Arne Bardalen** | NFLI |
| « | **Rune Bredesen** | SINTEF-MC |
| « | **Åsa Astervik** | VRD |
| GA Member (User partner) | **Frank Sagvik** | AKERSHUS |
| « | **Jon Iver Bakken** | HAFSLUND |
| « | **Morten Fossum** | STATKRAFT |
| « | **Jonny Stuen** | EGE |
| « | **Christer Forsberg** | VHN |
| « | **Hans Olav Midtbust** | ENERGOS |
| « | **Pål Jahre Nilsen** | CAMBI |
| « | **Knut Richard Kviserud** | JØTUL |
| « | **Egbert van de Schootbrugge** | GKAS |

**The Centre Management Team (CMT)** consists of the Centre Coordinator, the Deputy Centre Coordinator, the Centre Manager and the Sub-Project leaders. The CMT is led by the Centre Coordinator. The CMT organises regular meetings, as required for coordinating the activities in the Centre.

Table 3: Centre Management Team.

| Position | Name | Affiliation |
|---|---|---|
| **Centre Coordinator** | **Berta Matas Güell** | SINTEF-ER |
| **Deputy Centre Coordinator** | **Odd Jarle Skjelhaugen** | NMBU |
| **Centre Manager** | **Einar Jordanger** | SINTEF-ER |
| | **Alexis Sevault** | SINTEF-ER |
| **Biomass Supply and Residue Utilization** SP1 | **Simen Gjølsjø** | NFLI |
| **Conversion Mechanisms** SP2 | **Michaël Becidan** | SINTEF-ER |
| **Conversion Technologies and Emissions** SP3 | **Øyvind Skreiberg** | SINTEF-ER |
| **Sustainablitiy Analysis** SP4 | **Birger Solberg** | NMBU |
| **Knowledge Transfer and Innovation** SP5 | **Terese Løvås** | NTNU |
| **Value Chain Assessment** SP6 | **Anders H. Strømman** | NTNU |

**Scientific Advisors (SA)** were appointed in 2010, one for each Sub-Project, except SP0, SP5 and SP6. The four Scientific Advisors are shown in Table 4.

Table 4: Scientific Advisors.

| Sub-Project | Name | Affiliation |
|---|---|---|
| Biomass Supply and Residue Utilisation SP1 | Heikki Pajuoja | Dir. Metsäteho Oy |
| Conversion Mechanisms SP2 | Mikko Hupa | Prof. Åbo Akademi University |
| Conversion Technologies and Emissions SP3 | Michael J. Antal, Jr. | Prof. University of Hawaii |
| Sustainability assessments SP4 | Pekka Kauppi | Prof. Universitetet i Helsinki |

## Work Breakdown Structure (WBS)

The technical activities within CenBio are organized in six Sub-Projects (SPs), each divided into Work Packages (WPs). A separate SP is defined to separate the management and coordination activities from the technical work, under SP0. The WBS is shown in Figure 4.

Note that SP6 – Value Chain Assessment was planned during 2012 and started operating as from 1 January 2013.

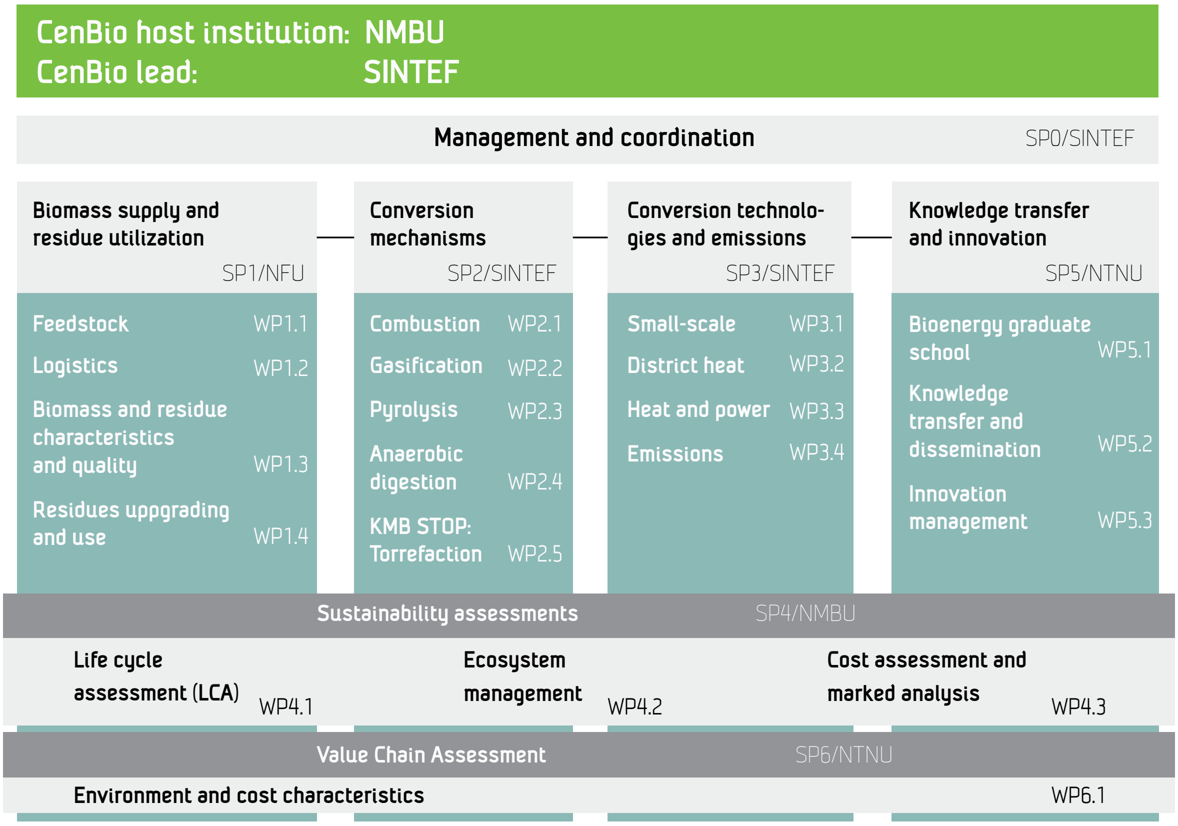


*Figure 4: Work Breakdown Structure.*

## Cooperation between partners

The research activities in CenBio are mainly performed at universities and research institutes at Ås and in Trondheim. One R&D partner, Vattenfall R&D based in Sweden, works in close cooperation with SINTEF Energy Research. In some Work Packages (WP), partners, both from Ås and Trondheim, participate and there is cooperation between different WPs. The number and nature of these internal collaborations leading to peer-reviewed publications (both journal and conference) are shown in Figure 5. Per February 2015, the total number is 76 internal collaborations leading to publications, and the trend clearly shows that the yearly number of internal collaborations steadily grows every year. The number of internal collaborations between Ås and Trondheim is also to be noted since it has been increasing every year and is a direct consequence of the work performed through CenBio.

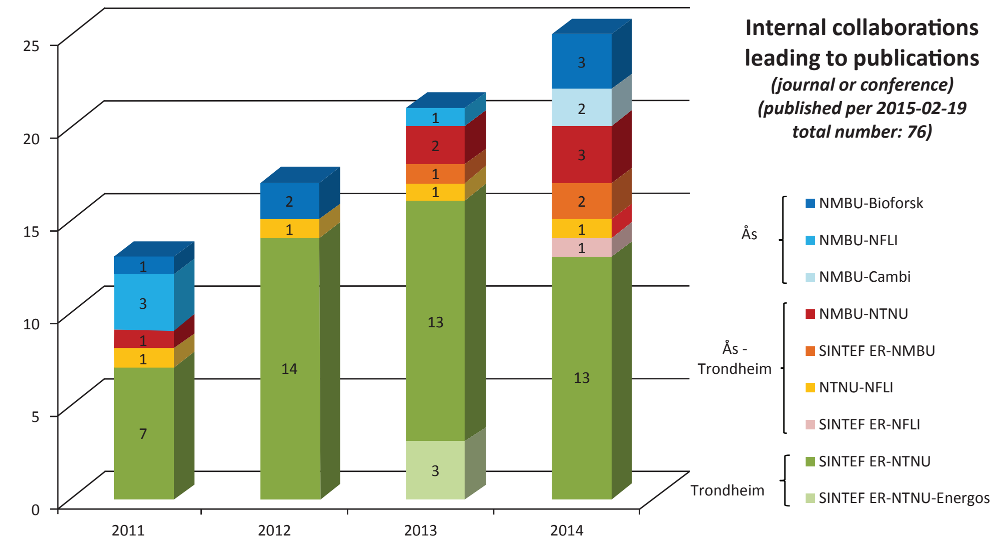


*Figure 5: CenBio internal collaborations leading to peer-reviewed publications (journal or conference).*

The User partners also contribute with in-kind research, and in some cases researchers from the universities or research institutes perform research at their installations. Some of those collaborations are also shown in Figure 5, notably with User partners Cambi and Energos.

The User partners also participate in the compilation of the Annual Work Plan for the coming year. Usually, the WP leaders prepare a draft based on input from the researchers active in each respective WP; the draft is either discussed in meetings where interested partners participate or in direct dialogue with representatives from the User partners.

During the first trimester every year, the Centre invites all partners to attend the CenBio Days, in conjunction with the General Assembly, where all partners are expected to participate. In addition, international experts and CenBio Scientific Advisors (SA) are invited to give state-of-the-art presentations. Since 2013, a second yearly meeting is organised with all the partners around October, with a special focus on the next Annual Work Plan.

In 2014, the CenBio Days took place in Lillestrøm on 26–28 March. Presentations from selected CenBio researchers, invited representatives from User partners and invited international researchers were given in plenary sessions. Special topics, such as value chain assessment (SP6), communication and innovations were discussed in plenary sessions. One of the Scientific Advisors gave a keynote presentation about bioenergy R&D in the USA. A site visit was also organised at the Akershus Energi Park.

The CenBio Strategic Days were organised on 29–30 October 2014 in Gardemoen to gather all the CenBio members. A visit of the bioenergy laboratories at Ås Campus was organised on the first day. This event, which first happened in 2013, enabled to discuss various topics of strategical importance for the Centre:

- Inputs for the Annual Work Plan 2015
- Value chain assessment (SP6): first round of results and scoping scenarios for 2015.

*Figure 6: CenBio Days 2014.* Photos: CenBio

# Management and Coordination

## General

The overall coordination activities are organized within a separate Sub-Project (SP0) – Management and Coordination. During 2014, the main activities consisted in reporting costs and progress, arranging coordination meetings, and coordinating the planning of future research activities (including the Foresight Process). Management within each SP or WP is the responsibility of respective SP- and WP leaders. In addition to those usual tasks, SP0 also organized the CenBio Days and the CenBio Strategic Day.

## Project management system – the CenBio eRoom

A project management system for CenBio was established in 2009, where all relevant documents are uploaded. Personnel from all partners have access to the CenBio eRoom. By 31 December 2014, more than 100 persons had access to the eRoom. The overall structure of the CenBio eRoom was described in the Annual Report 2011.

## Meetings

The Centre Management Team had nine meetings in 2014, and the Core Management Team met eleven times. The Executive Board had three meetings, in June, October and November, and the General Assembly met on 28 March in Lillestrøm. Most CMT meetings are arranged as teleconferences using eRoom for sharing documents and information.

## Deliverables list and Publication database

In order to keep track of planned deliverables including journal papers for review an Excel workbook is established. All deliverables are listed with a unique number. When a new annual work plan is approved, the associated list of deliverables is added to the workbook. Progress is updated regularly, and when the calendar year is ended, possible unfinished deliverables are transferred to the next year. Hence, finalised deliverables are documented in the remaining annual list, as shown in Table 24.

Following up the progress of journal papers/scientific articles that are subject to peer-review requires a more detailed system. Therefore, a separate database has been established in the eRoom. Status is indicated by one of these stages: planned, in progress, submitted, accepted, in press, published. The current status is shown in Figure 25.

# Biomass supply and residue utilization **SP1**

**Simen Gjølsjø**
***Leader of Biomass Supply and Residue Utilization***
Norwegian Forest and Landscape Institute

**Biomass supply and residue utilization SP1/NFLI**

| | |
|---|---|
| Feedstock supply | WP1.1 |
| Logistics | WP1.2 |
| Biomass and residue characteristics and quality | WP1.3 |
| Residues upgrading and use | WP1.4 |

In the bioenergy sector, reducing costs is essential. In SP1, we have focused on costs reduction in the supply chain. A model for the supply chain has been made, based on a number of characteristics of external factors like biomass quantity per harvesting site, transport distance distribution, and annual volume flow. The model estimates the total supply cost, including the cost of losses at terminal points due to delay and debris.

The focus is in quantification of biomass. A PhD work was finalized in 2014 to improve models and methods for solving *"Temporal and spatial harvest activities in forest planning".* The thesis also had a part about harvesting bioenergy in the forest in Oslo area.

Wood fuel quality is crucial for the economy and the daily operation in a heating plant. In 2014 NFLI acquired a NIR Spektron instrument for instantaneous moisture measurements of biomass. With the standard method, it takes 24 hours to determine the moisture content. With the new system it takes seconds. NFLI is testing the instrument to see if it is sufficiently reliable for buying and selling of biomass.

Pine is the second most important species in Norway. The inherent properties of pine have been analyzed in stem, bark and branches. Other analyzed properties are: density, heating value, chemical content and ash amount and ash behavior.

Characterization of ash and ways to utilize ash are getting more and more important. We are currently working with Norwegian Environmental Agency to revise the regulations for ash utilization. Today, it is not legal to recycle ash back to forestry, but in the new regulations it might be accepted.

Experiments have shown that commonly used methods for characterising plant available phosphorus (P-AL method) underestimate the amounts phosphorus in wood ash. We have applied different analytical methods to characterize P compounds in ash. This work is part of a PhD work.

## Feedstock supply – **WP1.1**

### Assessment of forest biomass

***To develop new methods and models that can be used in inventories for assessing forest biomass and to use these in the search for potentially available biomass resources for energy production at different institutional and geographical levels.***

Aaron Smith, a PhD student at NMBU, funded by CenBio through Norwegian Forest and Landscape Institute (NFLI), is working on improving the estimation of tree biomass in Norway. Aaron's advisors are Andreas Brunner (NMBU), Rasmus Astrup, Aksel Granhus, and Halvor Solheim (all NFLI). A first journal publication[1] derived new functions to estimate Norwegian birch total aboveground, stem, and crown component biomass. A second journal publication[2] used a novel terrestrial laser scanning (TLS) and cylinder fitting modeling (QSM) methodology to reconstruct the volume and 3-D structure (see Figure 7) of large root systems.

A third journal publication will derive the first below ground and whole-tree birch biomass func-

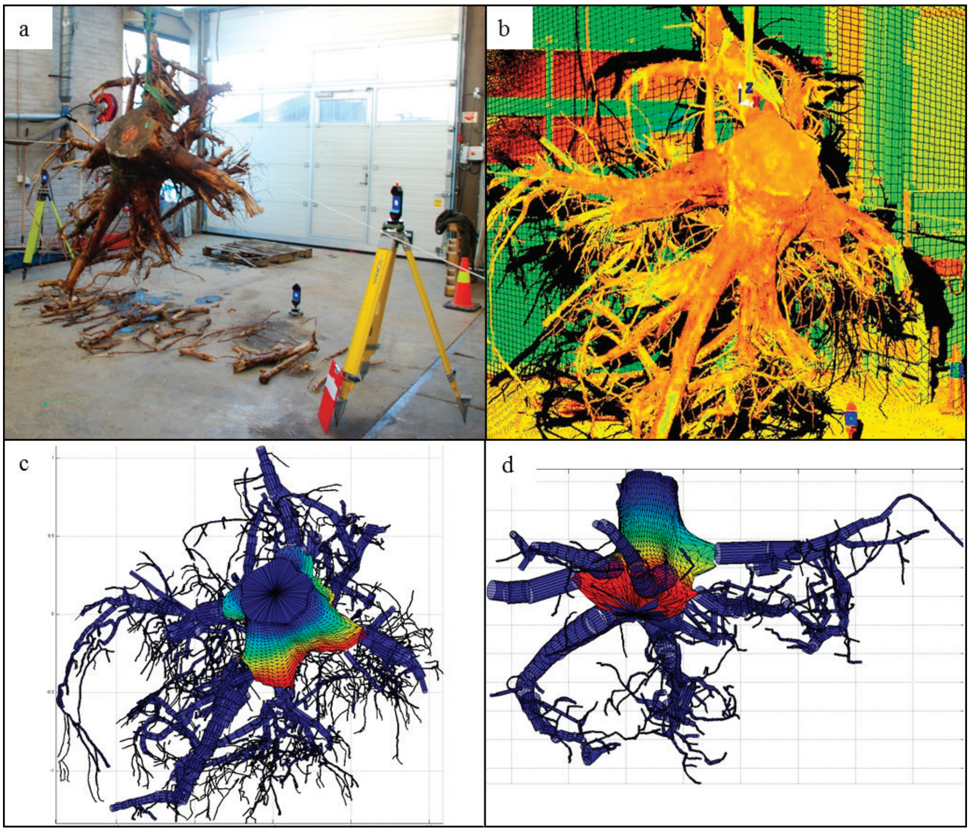


*Figure 7: Root system images: (a) Root system at scanning; (b) TLS point cloud data of a root system; (c) Top view of the QSM; (d) Bottom view of the QSM.*

tions in Norway and present novel belowground biomass estimation methodology. A fourth journal publication will investigate the influence of vertical stem wood-density variation on the national estimate of birch stem biomass in Norway. The body of work contributes to the improved estimation of biomass resources in Norway.

### Bio-economic optimisation

***To develop bio-economic optimisation methods and models handling the linkage between biological production, silvicultural management, economic behaviour, sustainability criteria and biomass supply and to use these in forest decision-support systems.***

Paulo Borges defended his PhD thesis in 2014 at NMBU on the following topic: *"Improved models and methods for solving temporal and spatial harvest activities in forest planning"*. He was funded by CenBio, and Prof. Tron Eid, Dr. Even Bergseng and Prof. Terje Gobakken were his supervisors. The two first papers[3,4], of Borges' thesis were related to methodological aspects of decision support systems (DSS), and how we, in an efficient way, can confront the complexity of planning ecosystems like forests. Borges applied simulated annealing in his research and provided valuable inputs improving the efficiency of the solving methods applied in DSS.

In the last part of the thesis[5,6], Borges focused on conflicts related to forest areas, which is valuable not only for commercial activities such as for example energy production, but also for recreational purposes and biodiversity. The nature areas surrounding Oslo (Oslomarka), which are the recreational home turf for a population of 1.2 mill. people, were used as case study area. Oslo municipality faces multiple challenges in their management, and in addition to improving solving methods related to maximum opening areas (law regulations do not allow large clear cuttings), Borges studied the effects of different environmentally oriented restrictions on available timber and biomass quantities from the municipality forest (Borges et al. 2014[5,6]). Results showed that the profitability may be reduced by up 20 % due to the restrictions. Still, however, a supply of 20-30 GWh annual energy from harvest residues can be provided from the municipality forest.

*(...) a supply of 20–30 GWh annual energy from harvest residues can be provided from the municipality forest.*

**A report[7] related to activities in COST (Action FP0804) on development and use of forest decision support systems in Norway was provided partly based on funding from Cenbio.**

## Logistics – WP1.2

The main focus during 2014 was to refine and publish a supply chain configuration and comparison model for woodchips from forest operations. Among other activities, a common method for estimation and presentation of machine costs were finalised[8] through the COST Action FP 0902. In addition, a paper on the supply of straw for small scale energy production under demanding climate condition was finalised[9].

The supply chain model was targeted for supporting decisions on supply chain configuration, based on a number of characteristics of external factors like cut object size distribution (biomass quantity per harvesting site), transport distance distribution, and annual volume flow. A sketch of the ten supply chain alternatives evaluated is provided below. The model estimates the total supply cost, including the cost of losses at terminal points due to decay and debris. A journal paper[10] on this topic was published in Forests.

According to the findings in the supply chain comparison, the use of terminals seems to add significant costs to the wood fuel supply. Supply chain alternatives where the wood is stored at forest roadside landing up to the time for usage is normally the most cost-efficient in total and having the least dry matter losses and cost of losses. However, these supply chain alternatives have some challenges regarding finding landings suitable for the heavy equipment presently

*Knowledge of the melting and gas-phase release behavior of ash is of important, in terms of predict and reduce ash-related problems in biomass-fired boilers.*

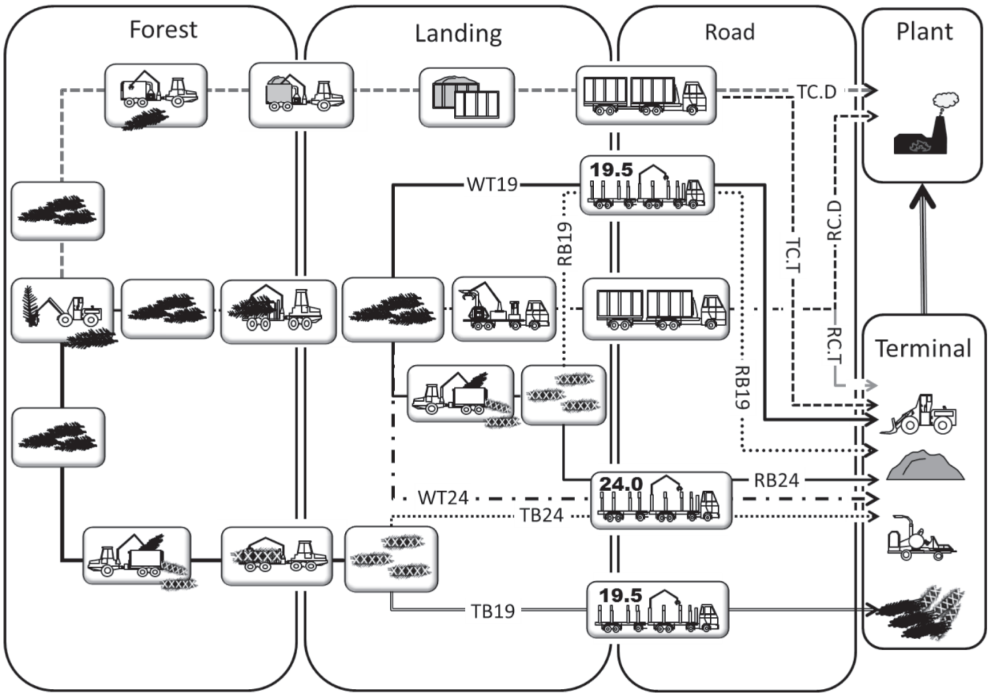


*Figure 8: Ten different supply chain alternatives illustrated.*

available for efficient chipping and transport, and matching the productivity of different mutually dependent actors when environmental characteristics changes. These particular challenges will be further addressed in the coming years within WP1.2.

## Biomass and residue characteristics and quality **WP1.3**

### Ash characterisation

Efficient and profitable biomass combustion is often limited by ash-related operational problems. Knowledge of the melting and gas-phase release behavior of ash is of important, in terms of predict and reduce ash-related problems in biomass-fired boilers. Different parts from Pinus sylvestris trees were studied in this study including stem wood, bark, branch base and twigs. Chemical composition and melting behavior of ashes from the four parts of P. sylvestris trees are investigated. A simultaneous thermal analyser (STA) was used to characterise the behavior of selected biomass fuels in oxidizing atmosphere. Ash melting process was identified as the distinctive endothermic peaks on recorded DSC curves. The results showed that the stem wood of pine contains higher contents of most of the ash forming matters than other tree parts. Chemical composition of ashes from four parts of the pine tree is dominated by element Ca, K, Mg, Mn, P and Si. The K, Na and P contents in the twigs are significantly higher than that of stem wood, bark, and branch base indicating high tendency of ash melting and slagging. STA experiments indicated that the melting process of the studied fuel ashes starts in the temperature range of 930-965 °C. Using scanning electron microscopy (SEM) equipped with an energy dispersive X-ray spectrometry (EDX), analysed results showed that the stem wood ash remains loose structure even after 1000 °C sintering treatment. But the ashes originated from top branch show sign of sintering at 1000 °C. The obtained results of present work can be considered as useful information within an industry interest for a prediction of the forest biomass ash melting behavior.

### Moisture content in wood

Since the dawn of mankind, control of moisture content in wood fuel for heating has been important to verify. Today, there is a need to measure, monitor and control the moisture content (MC) of biomass material from the raw material source, during transport and in heating plants. Accurate measurements of MC are, e.g., essential for sale and combustion of wood chips. The standard method to determine total MC is to dry the sample of chip at a temperature of 105 ± 2 °C until constant mass is achieved. This means long drying time, typically up to 24 hours and the method is not

*Since the dawn of mankind, control of moisture content in wood fuel for heating has been important to verify.*

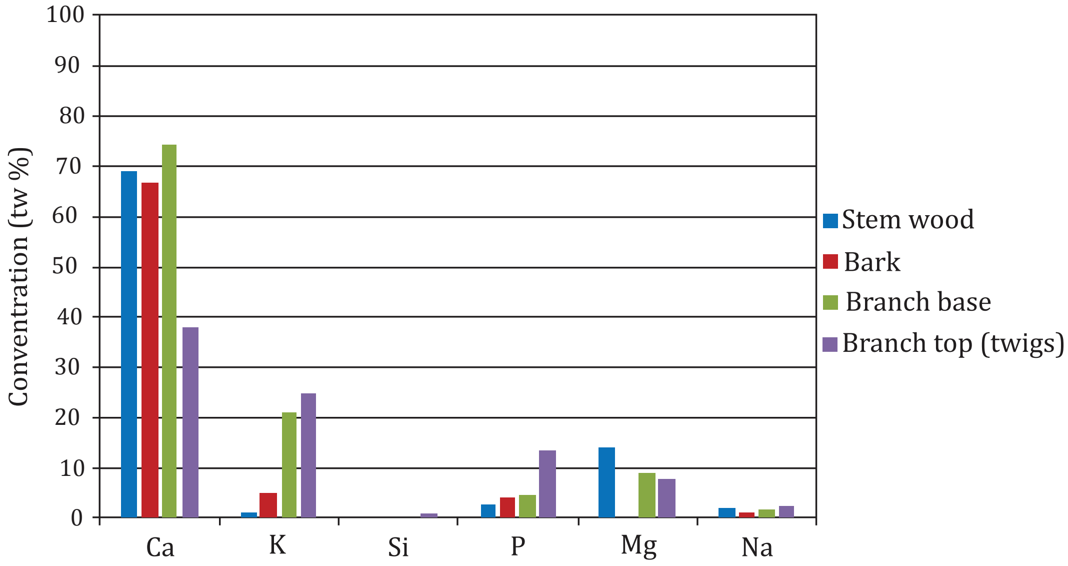


*Figure 9: Average elemental composition in the formed ashes (presented on a carbon- and oxygen-free basis, 10 areas with size 1 × 1 mm were scanned and analysed)*

very convenient to use in field work. The Norwegian company Prediktor has developed a near infra-red (NIR) Spektron analyzer (see Figure 9), especially designed and calibrated for measurements of MC in wood chips.

NFLI has studied the accuracy of the NIR Spektron instrument together with the Forestry Research Institute of Sweden (Skogforsk). NLFI and Skogforsk have measured stemwood and whole tree chips, both frozen and non-frozen. The results look promising for non-frozen material and more challenging for deep frozen chip material. Further analysis and measurements will give an indication if NIR technology should and can be used in measurements of MC in wood chips.

## Residue upgrading and use – **WP1.4**

In 2014, the main activities in WP1.4 represented a part of the PhD work of Eva Brod with the working title *"Phosphorus recycling: The use of Norwegian waste products as fertilizer in agriculture"*. Within CenBio, she has studied phosphorus (P) fertilization effects of respectively two different types of biomass ashes and anaerobic digestates. These residual products are end-products after combustion and anaerobic digestion of source-separated household waste, respectively.

*Figure 11: The moisture meter and chips in the bucket. Ready for measurements.* Photo: Eirik Nordhagen

## Chemical characterization of P in wood ash and anaerobic digestate

In spring 2014, we applied different analytical methods to the P-rich residual products including two biomass ashes and two anaerobic digestates with the aim to characterise P compounds and to explain observed P fertilization effects: Chemical fractionation schemes, X-ray diffractionation and 31P single-pulse solid-state NMR in cooperation with the University in Oslo. We found that P in biomass ashes and anaerobic digestate is mainly present as calcium phosphates of different solubility and that different P compounds can explain variable P fertilization effects of the residual products compared to mineral fertilizer.

*that a much higher proportion P in wood ash is plant available than the commonly used chemical extraction methods indicated*

## Research stay at ETH in Zürich, Switzerland

As part of her PhD work, Eva Brod stayed at ETH in Zürich, Switzerland for a 6-month research period between August 2014 and January 2015. The plant nutrition group at ETH is very experienced on using $^{33}P$ radioisotope methods for determination of plant available P in residual products. Eva Brod carried out a growth and an incubation experiment using a Norwegian wood ash among other P-rich waste types as fertilizer on a silt loam soil from Norway. The results will be published as a journal paper together with researchers from ETH Zürich.

## Publication of results obtained in 2013/2014

A draft of a journal paper based on results obtained in 2013/2014 was prepared in 2014. The draft will be submitted in early 2015. It describes the attempt to predict the P fertilization effects of residual products (including biomass ashes and anaerobic digestates) as studied by a pot experiment by standard chemical extraction methods. The results confirm our results from previous studies that a much higher proportion P in wood ash is plant available than the commonly used chemical extraction methods indicated. These results were described in a scientific paper on the use of wood ash as fertilizer to cereals that was accepted by Acta Agriculturae Scandinavica, Section B Plant and Soil Science in 2014.

*Figure 12: Eva Brod at ETH in Zürich Switzerland with barley plant fertilized by Norwegian wood ash on soil labelled with 33P radioactive P.*

# Conversion mechanisms **SP 2**

**Michaël Becidan**
***Leader of Conversion Mechanisms***

SINTEF Energy Research

**Conversion mechanisms SP2/SINTEF**

| | |
|---|---|
| Combustion | WP2.1 |
| Gasification | WP2.2 |
| Pyrolysis | WP2.3 |
| Anaerobic digestion | WP2.4 |
| KMP STOP: Torrefaction | WP2.5 |

**SP2 encompasses combustion, gasification, pyrolysis, anaerobic digestion (and torrefaction). The work is especially focused on low-quality feedstocks, which are central in increasing the bioenergy production in Norway. Challenging biomass includes forest and agricultural residues, organic waste and sewage sludge, which are all largely unexploited in Norway today.**

In 2014, SP2 activities were especially oriented towards User partners as they included:

- A full scale measurement campaign at Statkraft Varme Marienborg BtE plant with focus on N-chemistry ($NO_x$ formation)
- A technical workshop/seminar on ash that attracted 25 participants from over 15 R&D institutes and industry actors
- A conference article with SINTEF/Energos co-authorship detailing ash chemistry during gasification
- A complete study of the microbial community dynamics of a full-scale biogas reactor from EGE Oslo.

Furthermore, a PhD study on wet torrefaction was completed. It offered a great number of results and insights on this novel pre-treatment method.

## Combustion – **WP2.1**

### Measurement campaign at Statkraft Varme Marienborg

This activity is especially interesting and exciting for the following reasons:

- It is a cooperation between NTNU, SINTEF Energy Research and Statkraft Varme AS,
- It combines experimental field work and modelling activities in order to better understand and hence improve plant operation.

*It combines experimental field work and modelling activities in order to better understand and hence improve plant operation.*

The overall goal of this activity is to collect real-life data to be used for CFD (Computational Fluid Dynamics) modelling in order to improve plant operation on selected aspects. The first point of order was for all participants (academia, research institute and industry) to sit together and discuss in order to:

1. Define the targets to prioritise;
2. Evaluate the experimental possibilities (equipment available, etc.) and limitations;
3. Assess the modelling scope and constraints (necessary input, general assumptions, etc.).

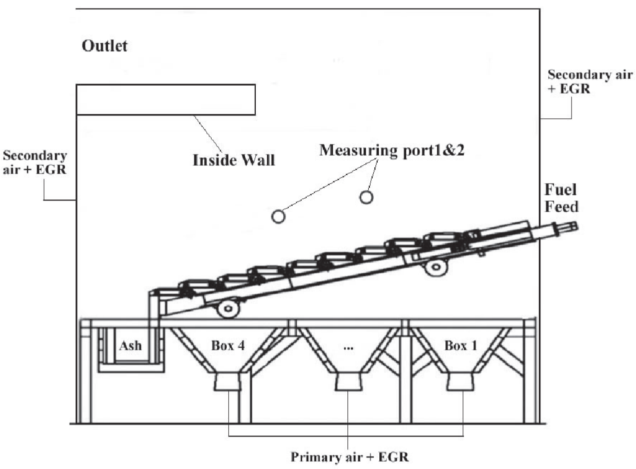


*Figure 12: Schematic of Statkraft Varme Marienborg BtE plant furnace (including measuring ports).*

Based on these discussions, the general layout of the experimental campaign at Statkraft Varme Marienborg 9MW BtE plant (delivering heat in Trondheim) and the general modelling framework were put in place. The main decisions and actions are summarized below.

Gas measurements will be carried out above the grate (about 50 cm) in the central section of the grate (see Figure 12 for approximate location) to measure primary/reactive species. Sampling and analysing gas at this position (ca. 1000+ °C) is especially difficult as many condensable species (tars, etc.), as well as particles will be present. Hence, a one-of-a-kind in-house designed heated sampling and filtering system (see Figure 13), especially developed for measurement in harsh environments, is to be used for the very first time. Previous experience with other (non- or partly-heated) systems shows that the sampling line is usually clogged after a few minutes. Hopefully, this will not be the case with this new device.

FTIR and GC will be jointly used for measurement. These methods, combined together, allow for the on-line quantification of the most relevant gas species, both minor and major components.

$NO_x$ precursors (i.e. mainly HCN and $NH_3$) will be the first focus as $NO_x$ emissions are one of the main concerns of this plant and BtE plants in general.

Figure 12 shows a general schematic of the furnace which consists of a rectangular container of dimensions 4.65m (length) × 3.1m (width) × 3m (height). Spruce wood (as briquettes) is used as the fuel and its initial properties, such as proximate and elemental analyses, are given in Table 5.

The CFD-DEM model is formulated based on an Eulerian-Lagrangian multiphase model, meaning that transport equations are solved for the continuous gas phase and each of the discrete particles is tracked through the calculated gas field. The integrated model, which includes sub-models for turbulence, heat and mass transfer, radiation, particle shrinkage, particle collision, pyrolysis, and heterogeneous and homogeneous reactions, is suitable for dense and reacting flows. The comprehensive description and detailed implementation issues of the model are available in an earlier publication[11].

Here, the integrated model will be firstly tailored to be used for the industrial-scale boiler at Marienborg, and will include additional reactions to account for $NO_x$ formation.

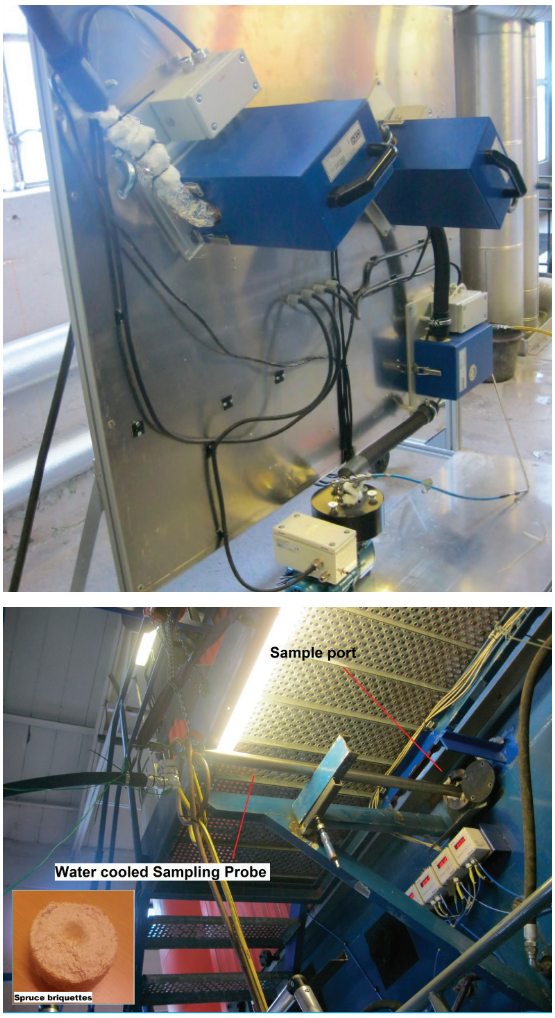


*Figure 13: In-house developed heated gas sampling (up) and filtering (down) system – on site at Marienborg).*

Initial calculations have been carried out and further refining of the model is underway. The next step will be validation of the model together with the collected experimental data (the experimental campaign started week 5 in 2015).

## Ash mini-seminar/workshop – Industrial challenges & R&D opportunities in Norway

Technical seminars/workshops are an ideal arena for researchers and industry actors to meet and exchange experience and knowledge. For 2014, the topic of ash was identified as an interesting one both for biomass- and waste-fired plants. This meeting was not meant to be a conference to present a lot of R&D results but rather a first platform for networking and discussions about the relevant ash topics to address today, as well as a springboard for future cooperation and coordinated actions.

The event was coorganised by SINTEF Energy Research and NFLI; both CenBio and non-CenBio partners were invited. Discussions on a broad variety of topics ensued:

- The situation today: What is not satisfactory? What could be improved? What are the main obstacles/challenges?
- Industrial needs/goals/strategies (long term/short term)?
- Possible actions for tomorrow: What do you expect from (1) the authorities; (2) R&D: what are the areas for research that need to be focused on? How can the R&D activities meet the industry needs?
- Technical axes: (1) feedstock ash characterisation; (2) ash behaviour during thermal conversion (corrosion, slagging, fouling) and solutions; (3) innovative recycling/uses (metal extraction, road building, stabilisation, agriculture, etc.)

Table 5: Proximate and elemental analyses of the fuel (wt.%).

| Proximate analysis (as-received) | | | | Elemental analysis (daf basis) | | | |
|---|---|---|---|---|---|---|---|
| Moisture | Ash | Volatile | Fixed carbon | C | H | O | N |
| 7.19 | 0.17 | 79.91 | 12.73 | 50.85 | 6.10 | 42.97 | 0.08 |

Key aspects considered included: economy/profitability/viability, environment and health/toxicity, climate, energy production, etc. The complete list of participants (about 25 total) shows the broad appeal of the topic:

- SINTEF Energy Research
- Norwegian Forest and Landscape Institute
- SINTEF Foundation (Materials and Chemistry)
- Bioforsk
- Norwegian University of Science and Technology
- SINTEF Byggforsk
- TreTeknisk Institutt
- NGI
- Statkraft Varme AS
- Hafslund Varme
- Tafjord Fjernvarme
- Energos AS
- EGE Oslo
- Norske Skog Skogn
- TerraTeam
- Fossli
- Statens vegvesen

## Gasification – **WP2.2**

### Ash chemistry conference article: cooperation between Energos AS and SINTEF Energy Research

This work is a joint conference article submitted for presentation at the ICheaP12 International Conference on Chemical and Process Engineering[12] and for publication in the Chemical Engineering Transactions (Level 1 publication channel). It is co-authored by SINTEF Energy Research and Energos AS and was accepted for publication (with request for minor revisions) on 3 February 2015.

This succinct thermodynamic study addresses the gasification chemistry of four chemical elements involved in ash-related challenges, i.e. Na, K, S and Cl. At typical temperatures for the process studied (Energos grate-based MSW gasification concept), the following main trends have been observed: (1) the phase distribution of these elements may change abruptly, i.e. within a narrow temperature range; (2) the main practical outcome of Point 1 is that it will be difficult to optimise a given process giving the versatility of chemistry vs. temperature, but stable operating conditions are preferable. Figure 14 and Figure 15 present some of the results discussed in the article.

Mitigating ash-related challenges (fouling, slagging, corrosion) is an arduous task and unambiguous results are seldom, given the complex multi-element chemistry and physical processes at play. Several methodologies (at various states of maturity) are available:

1. Additives, including “smart” mixtures. Aluminosilicates can prevent the formation of corrosive alkali chlorides that are replaced by alkali aluminosilicates that remain in the bottom ash, are inert and have a high melting point;

2. Process optimisation including design (air distribution, superheater parameters, etc.);

3. Extensive fuel characterisation to assess quality, pre-treatment and system requirements;

4. Boiler cleaning (sonic, explosive);

5. Materials development (corrosion resistant alloys, coatings);

6. Advanced systems (Oxygen Enhanced Combustion, etc.) including gasification and pyrolysis;

7. Prediction (modelling).

Other factors are interesting when considering ash-related challenges, i.e. heterogeneity/local conditions (concerning fuel properties and O distribution especially), as well as the fate of specific trace metals (Pb, Zn).

## Pyrolysis – **WP2.3**

In 2014, pyrolysis-related activities have been carried out through the CenBio spin-off KPN project STOP[13] (main focus: torrefaction, see WP2.5) and in the (non-CenBio financed) Energi X KPN project BioCarb+[14] (main focus: carbonisation). Both projects are led by SINTEF-ER.

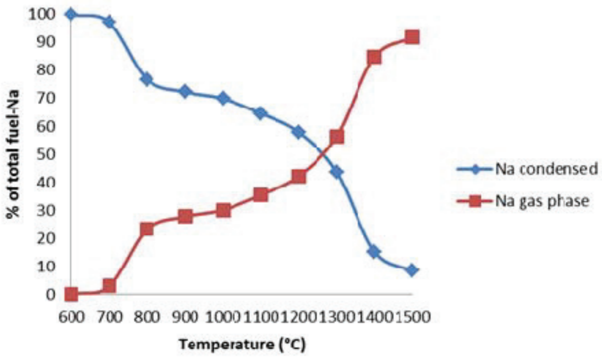


Figure 14: Phase distribution of Na.

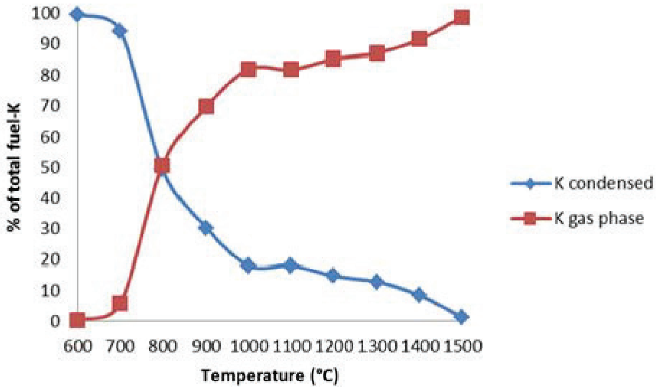


Figure 15: Phase distribution of K.

## Anaerobic digestion – WP2.4

### Microbial community dynamics in the Oslo EGE bio-digester

As an extension of previous microbial investigation on two biogas producing reactors, a microbial community dynamics of a full-scale biogas reactor Oslo EGE was studied over half-a-year using 454 pyrosequencing of 16S rRNA genes. The reactor (volume 3200 $m^3$) with an average hydraulic retention time (HRT) of 24 days, was fed constantly with source-separated food wastes from the Oslo region. It was operated primarily under mesophilic anaerobic condition but included a thermal hydrolysis step as a pretreatment.

**Representative results:**

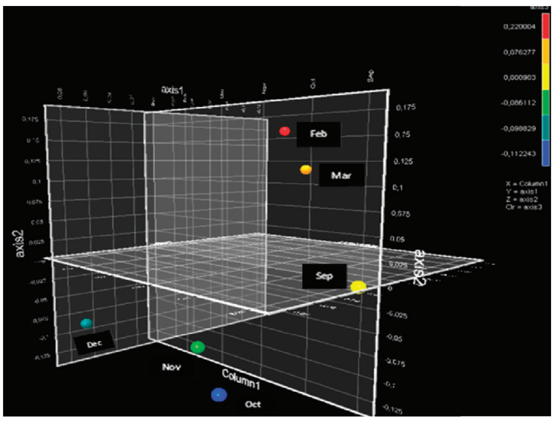


*Figure 16: NMDS plotting of microbial structure similarity; three clusters were generated of the samples from: Oct. Nov. and Dec; Feb. & Mar.; Sep.*

The samples for microbial analysis were collected monthly during Sep. to Dec. 2013 and Feb. & Mar. 2014. The collected samples were immediately stored at -20 °C until DNA extraction. For the sample preparation we used a DNA purification kit (Mo Bio) to improve the nucleic acid quality (minimize the PCR[15] inhibitors) and increase yield. This is a big step forward for us in a way that we could overcome the failure of capturing the archaeal groups during the previous trails.

*The results indicate that the changes of microbial communities' dominancy and diversity are correlated significantly with the nature and contents of the nutrients containing in the substrates.*

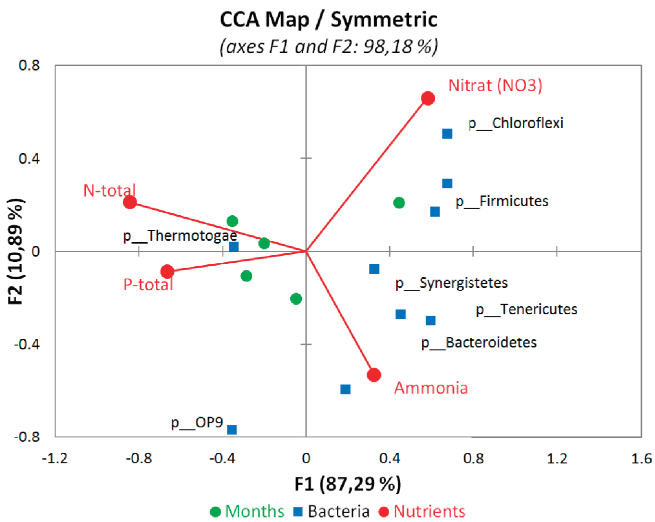


*Figure 17: CCA map of correlation between bacterial community with selected chemical measurements*

The pyrosequencing generated in total 92 774 sequences representing 18 phyla, 24 classes and 61 genera of Bacteria and Archaea. At phylum level, *Thermotogae, Bacteroidetes, Firmicutes* and *Euryarchaeota* represented the most important populations, while *Thermotogae* was detected as the most abundant phylum during the entire examined period. At the sub-distributed class level, *Thermotogae, Bacteroidia* and *Clostridia* presented predominantly. The bacterial profiles were started to change in February and March 2014 as *Thermotogae* dominancy was reduced while accompanied by the increasing of *Bacteroidia* and *Clostridia*. Bacterial diversity was comparably higher in February and March than in previous months. An interesting shift of dominant methanogen was observed from Methanosarcina to Methanosaeta from September to February 2014 gradually. Non-metric multidimensional scaling (NMDS) calculated based on the entire microbial similarity of all the samples revealed three clusters: March and February 2014; November, October and December 2013; September 2013. Canonical Correspondence Analysis (CCA) discovered that *Thermotoage* and *Methanosarcina* are closely associated with the amount of N and P total; *Chloroflexi, Firmicutes* and *Methanosaeta* are related well with Nitrate level; *Synergistetes, Bacteroidetes, Tenericutes and Methanosarcina* have the clear impact on ammonia production.

The results indicate that the changes of microbial communities' dominancy and diversity are correlated significantly with the nature and contents of the nutrients containing in the substrates. Different microbial groups show preferences in terms of targeting/degrading specific types of nutrients under certain conditions. Consequently, this determines the pathways by which the final methane formation is completed.

## KMB STOP: Torrefaction – **WP2.5**

In 2013, the CenBio spin-off project KMB STOP (STable OPerating conditions in biomass combustion plants) was completed, and in 2014 the STOP-financed PhD study was completed. The PhD study with the title *Wet torrefaction of biomass – Production and conversion of hydrochar* focused on torrefaction in water, so-called wet torrefaction.

Wet torrefaction (WT) is a promising method for pretreatment of biomass for use as fuel. The method involves the use of hot compressed water, within 180–260 °C approximately, as reaction medium. Like dry torrefaction (DT), which may be defined as mild thermal treatment of biomass within 200–300 °C, WT improves significantly the fuel properties of biomass. In addition, due to the use of water as reaction medium, WT is highly suitable for low cost biomass sources such as forest residues, agricultural wastes, and aquatic energy crops, which normally have very high moisture content.

The PhD candidate, Quang-Vu Bach, focused on fuel properties improvements during wet torrefaction, also in comparison with dry torrefaction. A number of publications have been written during the PhD work, whereof the following were included in the PhD thesis:

I. Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg, Gulaim Seisenbaeva. *Comparative assessment of wet torrefaction.* Energy & Fuels **2013**, 27, 6743-6753.

II. Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg, Roger A. Khalil, Anh N. Phan. *Effects of wet torrefaction on reactivity and kinetics of wood in air combustion*. Fuel **2014**, 137, 375-383.

III. Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg, Thuat T. Trinh. *Effects of wet torrefaction on pyrolysis of woody biomass fuels.* **Submitted**.

IV. Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg. *Torrefaction of forest residues in subcritical water.* **Submitted**.

V. Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg. *Effects of $CO_2$ on wet torrefaction of biomass.* Energy Procedia **2014**, 61, 1200-1203.

VI. Quang-Vu Bach, Nevena Mišljenović, Khanh-Quang Tran, Carlos Salas-Bringas, Øyvind Skreiberg. *Influences of wet torrefaction on pelletability and pellet properties of Norwegian forest residues.* Annual Transactions - The Nordic Rheology Society **2014**, 22, 61-68.

The major findings from the studies reported in the PhD thesis are:

- Both reaction temperature and holding time have significant effects on the mass yield, energy yield, and fuel properties of the hydrochar.
- Pressure also enhances the torrefaction rate; however, the effect becomes marginal above a certain pressure.
- Feedstock particle size slightly affects the yield and fuel properties of the hydrochar.
- Ash content of biomass fuel is significantly reduced by WT. Given the same solid yields, WT requires significantly lower torrefaction temperatures and shorter holding times than DT.
- Given the same solid yields, solid biomass fuels upgraded via WT have greater heating values than via DT.
- Hardwood is more reactive and produces less hydrochar than softwood in identical WT conditions.
- Forest residues are more reactive than stem woods in identical WT conditions.
- WT in $CO_2$ enhances the torrefaction process, but reduces the heating value of hydrochar, compare to WT in $N_2$.
- Overall, WT has positive effects on the fuel properties of biomass.

The interested reader can find more information in the PhD thesis:

Quang-Vu Bach (2015). *Wet torrefaction of biomass – Production and conversion of hydrochar.* PhD thesis 2015:20. Norwegian University of Science and Technology.

Associate Professor Khanh-Quang Tran at NTNU has been the main supervisor while Chief Research Scientist Øyvind Skreiberg at SINTEF Energy Research has been the co-supervisor, and the STOP project leader.

During the 4 years of torrefaction research in STOP and CenBio, a large amount of research has been carried out. The results, the lessons learned and the prospects of torrefaction have been summarized in the STOP handbook, shown in Figure 18, available at the STOP webpage[16], where an up to date publications list from the STOP project is available.

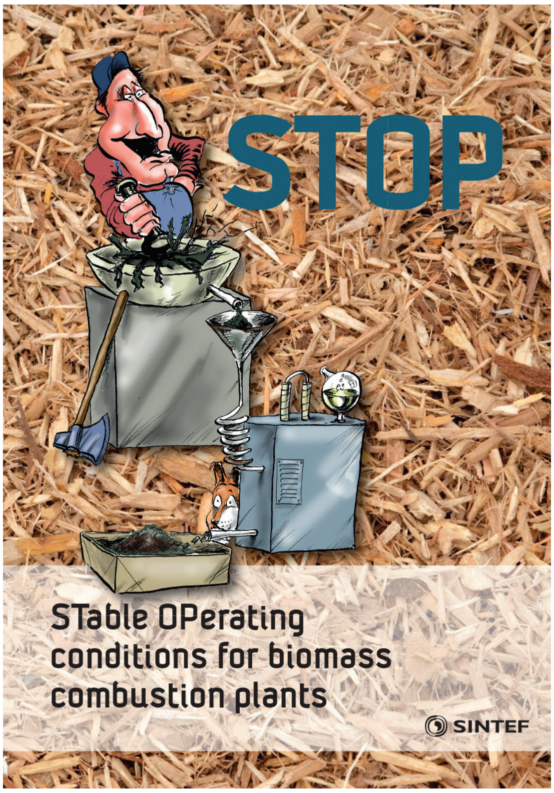


*Figure 18: The STOP handbook.* *Ill.: SINTEF/Kjetil Strand*


# Conversion technologies and emissions **SP3**

**Øyvind Skreiberg**
***Leader of Conversion Technologies and Emissions***

SINTEF Energy Research

**Conversion technologies and emissions SP3/SINTEF**

| | |
|---|---|
| Small-scale | WP3.1 |
| District heat | WP3.2 |
| Heat and power | WP3.3 |
| Emissions | WP3.4 |

**The work in SP3 involves residential wood/pellet stoves, district heat, heat and power and emissions. The objective is to demonstrate that all the energy conversion efficiencies listed in the Bioenergy Vision 2020 (cf. *CenBio Annual Report 2012*) are practically and economically feasible, as well as environmentally benign.**

- **WP3.1** – Small-scale (stoves): Energy efficiencies of 0.85 will be demonstrated for selected fuel fractions, not as peak efficiencies, but as average efficiencies including cold-starts.
- **WP3.2** – District Heat: Efficiencies of 0.9 will be demonstrated, but here the losses in heat distribution are excluded, since heat distribution falls outside the CenBio scope of work.
- **WP3.3** – Heat and Power: The feasibility of efficiencies of 0.95 will be demonstrated for the combined production of heat and power.
- **WP3.4** – Emissions: It will be demonstrated how emissions from Biomass-to-Energy plants may be reduced to below half of present regulations.

Making wood combustion cleaner is essential, especially for the local air quality. The CenBio goal for particle emissions from residential wood stoves is 2.5 g particles per kg dry wood, and increased energy efficiency. The part load issue is also important, in addition to standardisation of testing methods related to EU directives.

SP3 covers as well the demonstration of increased efficiency and innovative solutions for district heat. Working within networks, such as IEA Task 32 – Biomass combustion and co-firing, and IEA Task 36 – Integrating energy recovery into solid waste management systems, and together with Avfallsforsk (national research arena) and Prewin (European industrial network for Waste to Energy, WtE), is crucial to stay at the forefront of R&D and to understand the industry needs.

Innovative concepts for combined heat and power (CHP) are also investigated, such as the ChlorOut technology developed by Vattenfall. ChlorOut is a concept reducing corrosion and fouling for biomass-fired boilers, as well as $NO_x$, CO and dioxin emissions. The concept has been tested at the Jordbro biomass combustion plant in Sweden.

For each conversion technology investigated within SP3, issues related to emissions are in the spotlight. They are investigated through four approaches:

- Plant emissions mapping (e.g., Energos/ Hafslund WtE plant at Borregaard in 2012 and Akershus Energi bioenergy plant at Lillestrøm in 2014);
- CFD modeling;
- Experimental studies;
- Literature surveys (e.g., $NO_x$ reduction methods).

***Innovations*** from SP3 are initially expected in the following areas:
- New efficient clean-burning stoves and fireplaces;
- Concepts for ultra-efficient district heating plants, possibly utilizing biogas and solid waste in synergetic combination;
- Concepts for heat and power plants with close to 100 % combined energy efficiency;
- New recipes for low-emission plants.

## Small-scale wood/pellet stoves – **WP3.1**

Today, small-scale wood combustion in wood stoves accounts for close to half of the bioenergy use in Norway, and the use of wood logs in small-scale units and pellets in pellet stoves is expected to increase substantially towards 2020. The goal of this work is to more than double the energy output from those units within 2020. That means more than a double energy output from these units compared with today. This demands increased efforts both with respect to emission reduction and efficiency increase to prevent increased amounts of harmful emissions and increased negative health aspects.

The objectives of WP3.1 are to:
- Develop innovative new efficient clean-burning stoves and fireplaces;
- Reduce particle emissions by 75% compared to the present national emission requirements;
- Increase energy efficiencies from 75% up to 85%.

Since the utilisation of firewood is expected to substantially increase within the next decade, it is essential to ensure that harmful emissions (e.g., particles) are minimized, and that national requirements and regulations are uphold and improved. Those considerations should not be relaxed by new EU directives not taking into account the special Norwegian conditions. Partial load performance is very important, since firing at partial load will be the typical situation in Norway. Standardisation of testing methods is then a key issue, through active participation in the international standardisation work related to new EU directives.

*Since the utilization of firewood is expected to substantially increase within the next decade, it is essential to ensure that harmful emissions*

Development and testing of new and improved combustion chambers and solutions for improved combustion and reduced emissions caused by incomplete combustion are the key research activities in WP3.1. The focus is primarily on various types of wood stoves (including light heat storing units), but also fireplace inserts, pellet stoves and combined units. Key aspects are efficiencies, cost-efficiency, emissions, fuel flexibility, fuel quality and user-friendliness.

### Standardisation work

Several standards and regulations setting emission measurement methods are currently aiming at significantly stricter emission limits for point source heating applications like wood stoves. The most important among these are the Ecodesign Directive, the European standard (CEN), The German DIN (Deutsches Institut für Normung) and DINPlus method, the German BImSchG (Bundes-Immissionsschutzgesetz) regulations as well as the Nordic Ecolabelling of stoves. A working group (LOT20) has been given a mandate to assess whether it is appropriate to set stricter Ecodesign requirements for energy efficiency and for emissions of particulate matter (PM), organic gaseous compounds (OGC), CO and nitrogen oxides ($NO_x$). The Ecodesign requirements were recently approved in September 2014. The new requirements will be operative from **1 January 2022**.

The new requirements for seasonal space heating energy efficiency for typical solid fuel wood stoves shall be no less than 65 %. The seasonal space heating energy efficiency shall be calculated as the seasonal space heating energy efficiency in active mode (based on the net calorific value of the fuel at nominal heat output) corrected by contributions accounting for heat output control, auxiliary electricity consumption and permanent pilot flame energy consumption.

When it comes to emissions of PM from closed fronted solid fuel local space heaters, these shall not exceed 20 mg/Nm$^3$ at 13 % $O_2$ when measured with a heated filter (first method/current European method) at nominal load as well as at part load if appropriate. When measured by the second method (Norwegian method), i.e. over the full burn cycle using natural draft and a full flow dilution tunnel with particle sampling filter at ambient temperature, the requirements are 5 g/kg (dry matter). When measured by the third method (English method), i.e. PM sampling over a 30 minutes period, using a fixed draft of 12 Pa and a full flow dilution tunnel as well as either a particle filter at ambient temperature or an electrostatic precipitator, the requirements are 2.5 g/kg (dry matter). For OGC, CO and $NO_x$ the requirements are 120 mgC/Nm$^3$, 1500 mg/Nm$^3$ and 200 mgN/m$^3$ expressed as $NO_2$, all values taken at 13% $O_2$. Additional requirements for product information/technical documentation have also been formulated.

*The increased stringency of these European standards will at some point have to be reflected in the Norwegian standard.*

The increased stringency of these European standards will at some point have to be reflected in the Norwegian standard. It is therefore expected that the Norwegian standard, NS3059, which have had the same emission limits since 1998, will have to tighten up its current weighted emission limit of 10 g/kg, possibly down to 2-5 g/kg. The maximum allowed emission of 20 g/kg will also probably have to be reduced with at least 50 % or more, down to 5-10 g/kg. Emission limits for OGC and CO will also probably be included as provided by the new Ecodesign requirements.

## KMB StableWood – in-kind project in CenBio

In 2014, the CenBio in-kind project KMB StableWood (New solutions and technologies for heating of buildings with low heating demand: Stable heat release and distribution from batch combustion of wood) was completed.

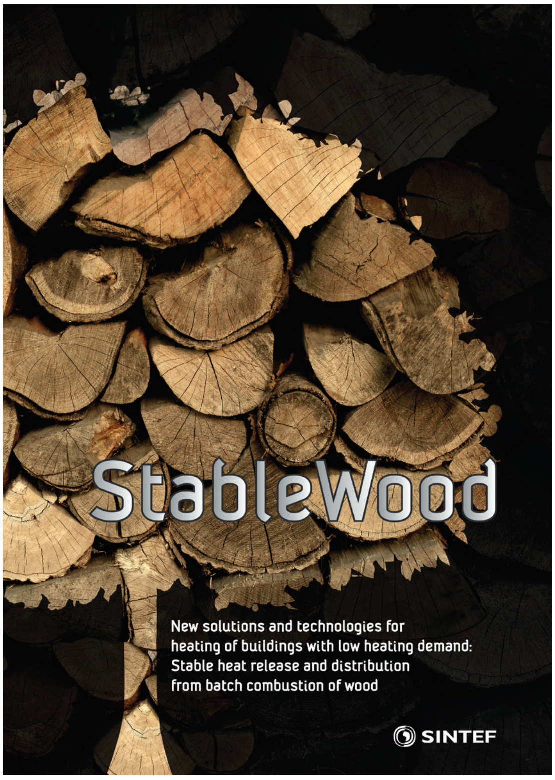


*Figure 19: The StableWood handbook.*

*Cover: Shutterstock/Astrid B. Lundquist*

During the 4 years of wood stove research in StableWood, a large amount of research has been carried out. The results, the lessons learned and the prospects of wood stoves in future's energy efficient buildings have been summarized in the StableWood handbook, shown in Figure 19, available at the StableWood webpage[17], where an updated publications list from the Stable-Wood project is available.

## District heat – **WP3.2**

This work package focuses on Waste-to-Energy (WtE) challenges. In 2014, the activity was related to the future of Norwegian WtE as well as participation in international networks, such as the IEA Bioenergy Task 36[18] *(Integrating Energy Recovery Into Solid Waste Management Systems).*

### Norwegian Waste-to-Energy (WtE) in 2030: Challenges and Opportunities

This work is a joint conference article submitted for presentation at the ICheaP12 International Conference on Chemical and Process Engineering[12] and for publication in *Chemical Engineering Transactions* (Level 1 publication channel). It is co-authored by SINTEF Energy Research, Statkraft Varme AS, Hafslund ASA, EGE Oslo and Energos AS and was accepted for publication (with request for minor revisions) on 3 February 2015.

The Norwegian Waste-to-Energy (WtE) industry faces a difficult situation on many levels:

- An internationally open and competitive market with significant export of both MSW (Municipal Solid Waste) and C&I (Commercial & Industrial) waste to Sweden,
- Low energy revenues reduce profitability,
- A limited national market (both concerning district heating and industry customers),
- Questions about $CO_2$ footprint,
- A more and more stringent regulative framework.

All that comes in addition to an array of technical challenges associated with waste as a fuel for combustion applications.

This work is a short discussion of both challenges and opportunities, for the Norwegian 2030 WtE industry. The authors are from the three largest WtE actors in Norway, a WtE technology provider and a leading R&D institute. The reflection axes are articulated along three questions:

1. What are the unique advantages offered by WtE to the Norwegian society?
2. What are the challenges faced by WtE in Norway?
3. What are the novel aspects that will be essential for Norwegian WtE to take into account in the coming years?

*During the 4 years of wood stove research in StableWood, a large amount of research has been carried out.*

The Norwegian WtE sector is facing great challenges especially low profitability due to international competition and low energy prices. But an evolution (a revolution?) towards new products, new markets, boost of energy sales and a stronger role in material recycling may well ensure its central place in a circular, renewable and sustainable economy.

## Heat and power – **WP3.3**

### CenBio aims for close to 100 % combined energy efficiency

Heat and power plants based on waste and biomass including also residues (e.g., sawdust) and upgraded fuels (e.g., pellets), are complex and challenging plants compared to most other heat and power technologies. This is due to the influence of the fuel on plant performance and economy. Small- to large-scale heat and power (CHP) plants are key technologies for an increased and efficient bioenergy utilization in Norway and worldwide. The objective of this WP is to develop innovative concepts for heat and power plants with close to 100 % combined energy efficiency.

Industrial biomass heat based on combustion of forest/wood residues is important in, e.g., the paper and pulp and the wood processing industry, while municipal solid waste (MSW) is important in waste-to-energy plants. In both cases, there is a potential for significant improvements. It is essential to:

- Assess the potential for efficiency improvements through improved combustion process control and process integration in industrial heat plants, and to assess the cost-efficiency potential of this,
- Assess the potential for emission reduction through efficiency improvements, fuel modifications and operational changes.

Several technology options exist for CHP plants (e.g., steam turbines, gas turbines, gas engines, Organic Rankine Cycle (ORC), Stirling engine, etc.) suitable for different plant sizes. However, they differ with respect to achievable efficiencies, operational reliability and costs. In addition, combinations of different CHP technologies can be applied to further increase the electric efficiency, e.g., combined cycles or gasification in combination with ORC. Hence, for a significant introduction of biomass- and MSW-based CHP in Norway, it is essential to assess the suitability of the existing technologies and the potential for further improvements with respect to cost-efficiency and emission abatement, including framework conditions, and operational optimization. In 2012, a pop-tech. article on the status of biomass CHP in Norway, and the way forward, was published in Xergi[19]. The list below shows the main ideas of the article:

*The objective of this WP is to develop innovative concepts for heat and power plants with close to 100 % combined energy efficiency.*

- The power production from biomass and waste reaches a significant level in Norway today, with about 0.4 TWh per year.
- That is made possible due to the low cost of fuel, or even its negative cost, e.g., MSW.
- The dominating technology is steam turbine for solid biomass, with one steam engine as the only exception.
- The only technology is gas engine for biomass derived gas (landfill gas or biogas).
- The possibility of increased electricity generation from biomass will depend heavily on economic framework conditions.
- The introduction of green certificates in Norway, through the common Swedish-Norwegian green certificate market is an incentive for increased electricity generation from biomass, though, with a fluctuating value of about 15-20 øre/kWh, this is still insufficient, notably to defend investment in small-scale CHP plant in Norway (< 10 MW fuel effect), unless:
  - The fuel cost is very low, or
  - The framework conditions for small- and especially micro-scale CHP is significantly improved (investment support, etc.).
- Continuous focus on fuel cost reduction is required to help improve the CHP plant economy.

Operational problems during biomass combustion can arise in the presence of certain elements such as alkali and chlorine (Cl) in the fuel. These problems are often described as alkali related and they include deposit formation and superheater corrosion. High levels of potassium chloride (KCl) in the flue gas often result in enhanced deposit formation, while high content of Cl in deposits may accelerate superheater corrosion. The main strategies to reduce alkali related problems are co-combustion and sulphur/sulphate containing additives.

Special attention in this WP is directed to implementation and evaluation of the so-called ChlorOut concept in a full-scale boiler in Jordbro designed for wood fuels, e.g., demolition wood and forest residues (cf. Figure 20). It is a BFB boiler, 63 $MW_{th}$, 20 $MW_{el}$, with the steam data 470 °C /80 bar. The implementation was performed as a cooperation between Vattenfall Research and Development AB (VRD) and Vattenfall AB, BU Heat (Heat). The ChlorOut concept consists of IACM, a device for on-line measurements of KCl in the flue gas, and a sulphate-containing additive that converts the alkali chloride (i.e. KCl) to a less corrosive alkali sulphate. The additive applied is often Ammonium Sulphate (AS) and it can also have an impact on certain other emissions including $NO_x$ and CO.

The major achievements from 2010 until February 2015 are summarised below. A permanent injection system for the ChlorOut concept has

*Figure 20: The Jordbro power plant.* *Photo: Vattenfall*

been installed by Heat and it was fully implemented in regular operation of the boiler during 2014. Prior to the permanent installation, measurement campaigns were carried out by VRD to optimise the dosage of AS regarding position, quantity, and maximal simultaneous reduction of especially KCl and $NO_x$. Additionally, the effect of AS injection was verified by short-term measurements with deposit probes. These results revealed that addition of AS reduced the content of KCl in the flue gases and also Cl in the deposits. Consequently, these measurement campaigns supported the implementation of the ChlorOut concept as a strategy to reduce the corrosion rate of the superheaters in the boiler in Jordbro. The permanent installation has been further evaluated with a somewhat widened approach and the most interesting results were obtained during long-term corrosion probe measurements with and without injection of AS. Here, the corrosion rate was significantly lowered with the ChlorOut concept. Certain aspects on the flue gas chemistry of KCl, NO and CO during injection of ammonium sulphate were also evaluated and these results are summarised in a conference paper which will be presented at the 22nd FBC Conference at Åbo Akademi[20] in June 2015.

## Emissions – **WP3.4**

### CenBio develops new concepts for reduced emissions

Air contaminants generated from combustion processes include sulphur oxides, particulate matter, carbon monoxide, unburned hydrocarbons and nitrogen oxides ($NO_x$).

Emissions from waste and biomass combustion are a continuous concern and continuous efforts with respect to emission minimisation are needed in order to ensure that the planned/future increase in bioenergy use is environmentally benign. Stricter regulations are expected in the future for WtE (waste-to-energy) and BtE (biomass-to-energy) plants, and also for wood stoves.

Reduction of harmful emissions from different combustion units are addressed in this work package. Based on advanced tools and improved methods, new concepts for reduced emissions will be developed. The objectives of WP3.4 are to:

- Mainly, develop new recipes for low-emission plants,
- Develop numerical tools and methods required to study concept improvements,
- Get increased insight into mechanisms for $NO_x$ formation and reduction,

- Define state-of-the-art for $NO_x$ reduction measures in WtE and BtE plants,
- Map emissions for one specific plant by carrying out extensive measurements,
- Map the emissions for BtE plants.

The activities in CenBio to obtain these objectives include:
- Plant emission mapping,
- Emission modeling (Computational Fluid Dynamics),
- Detailed chemical kinetics evaluation (CHEMKIN, DARS, COMSOL),
- Detailed experimentally studies using advanced measurement methods (see also WP3.1 and WP2.1).

## Emission mapping

Emission mapping for WtE and BtE full-scale plants is carried out through literature survey, collection of available data from the CenBio partners and experimental activity. In 2011, data received from the CenBio partners through an extensive questionnaire were compiled, and the need for new measurements was identified. Based on this background work, a plant was selected. The mapping campaign was carried out in June 2012 at the Hafslund WtE plant in Sarpsborg (Norway), which is Energos' technology. State-of-the-art measurement diagnostic equipment (FTIR, GC – see Figure 21) was utilised to measure gas concentrations at several positions within the primary and secondary chamber. The mapping campaign was carefully planned and prepared in close cooperation with Energos AS, a necessity to be able to perform advanced measurements and obtain high quality results.

*Figure 21: FTIR gas sampling and conditioning unit.* *Photo: Sascha Njaa, SINTEF*

The planning of a similar measurement campaign to be carried out at the Akershus Energi BtE-plant was going on in 2013. Extensive emission measurements such as those have hardly been carried out earlier at Norwegian BtE plants. This campaign was carried out spring 2014.

The mapping will serve as a basis for concept improvements, both numerical and experimental, as well as verification of CFD calculations and basis for model improvement. A new mapping may be carried out to verify the emission level if a new concept or improved conditions are included at the plant.

## Emission modeling

Tools and methods to study emissions from biomass and waste conversion units will be developed. CFD modeling will be an essential part of this work, and combined with detailed chemical kinetics for the gas phase reactions, which is a necessity when modeling fuel $NO_x$ formation and reduction at low to moderate temperatures, this gives quite comprehensive calculations and detailed results.

In 2012, a characteristic geometry (the SINTEF multi-fuel reactor) was set up in the CFD tool Fluent to study $NO_x$ formation. A chemical kinetics mechanism developed in WP2.1 was implemented in the CFD tool. A representative syngas composition was selected and initial calculations performed. The outcome is a numerical tool that can be used to study $NO_x$ emissions and $NO_x$ reduction potential from biomass conversion.

In 2013, comprehensive modeling work was started to assess the $NO_x$ reduction potential in the multi-fuel reactor using CFD, which is compared with earlier experimental results. This work was finalized with a journal publication manuscript in 2014 with the title "Numerical simulations of staged biomass grate fired combustion with an emphasis on $NO_x$ emissions", to be presented at ICAE 2015 and published in the international journal *Energy Procedia*.

In the paper we studied $NO_x$ emissions from biomass combustion, with the objective to demonstrate the applicability of stationary computational fluid dynamics simulations, including a detailed representation of the gas phase chemistry, to a multi-fuel lab-scale grate fired reactor (the multi-fuel reactor), shown in Figure 22, using biomass as fuel. In biomass combustion applications, the most significant route for $NO_x$ formation is the fuel $NO_x$ mechanism. The formation of fuel $NO_x$ is very complex and sensitive to fuel composition and combustion conditions. And hence, accurate predictions of fuel $NO_x$ formation from biomass combustion rely heavily on the use of chemical kinetics with sufficient level of details. In the work we used computational fluid dynamics together with three gas phase reaction mechanisms; one detailed mechanism consisting of 81 species and 1401 reactions, and two skeletal mechanisms with 49 and 36 species respectively. Using the detailed mechanism (81 species), the results show a high $NO_x$ reduction at a primary excess air ratio of 0.8, comparable to the $NO_x$ emission reduction level achieved in the corresponding experiment, demonstrating both the validity of the model and the potential of $NO_x$ reduction by staged air combustion.

The next step could be a further development in order to study mixing behavior, combustion and emissions in furnaces and to develop new concepts or optimising existing processes, combined with measurements for existing plants or combustion units (e.g., wood stoves).

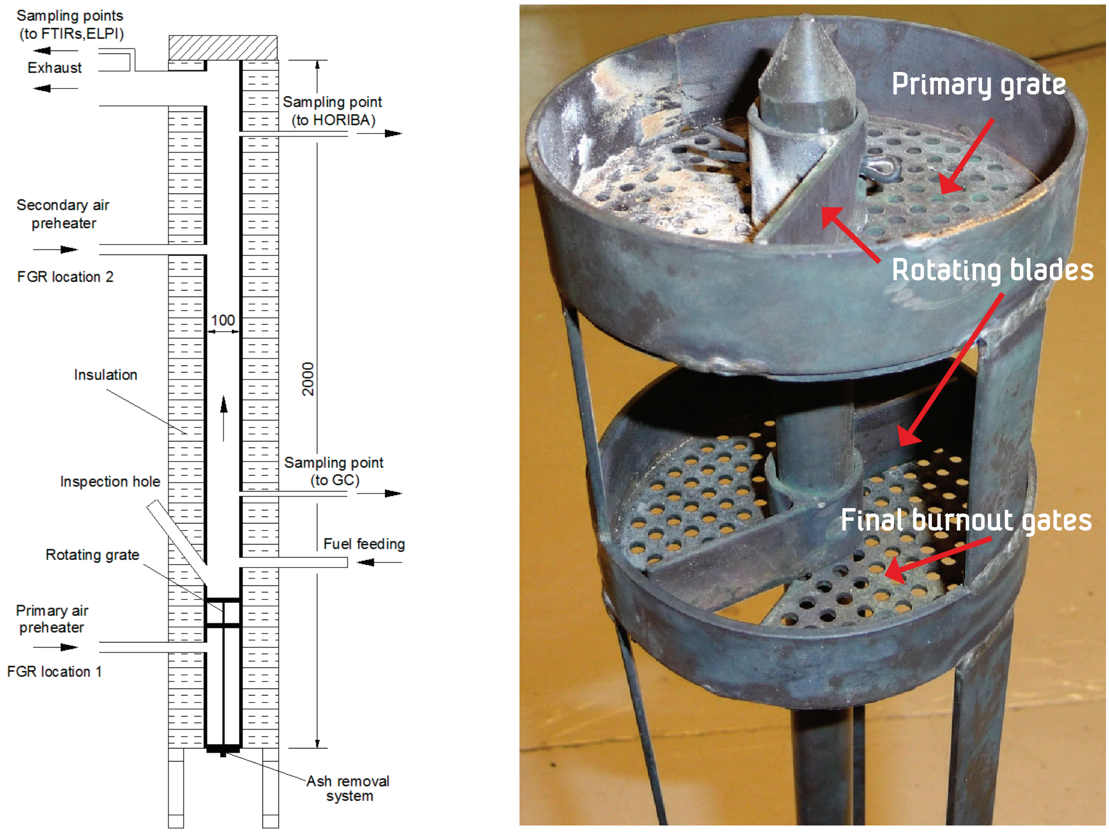


*Figure 22: The multi-fuel reactor and the two-level grate system.*

# Sustainability analysis **SP4**

**Birger Solberg**
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NMBU – Norwegian University of Life Sciences

**Sustainability assessments SP4/NMBU**

| | |
|---|---|
| Life cycle assessment (LCA) | WP4.1 |
| Ecosystem management | WP4.2 |
| Cost assessment and market analysis | WP4.3 |

**SP4 focuses on the establishment of documentation on the markets for forest biomass and the sustainability of bioenergy value chains. SP4 is divided between extended Life Cycle Assessment (LCA), ecosystem management, and work on costs, markets, policies and integrated sustainability analyses.**

Among the highlights from SP4 in 2014, the following one from WP4.2 should be mentioned:

Regarding the effects of forest harvesting for bioenergy on forest carbon stocks, there is, at present, an uncertainty gap between the scientific results and the need for practically useable management guidelines and other governance measures. This gap might be bridged by expert opinions given to authorities and certification bodies. Results suggest that sustainable use of the forests as a source of feedstock for bioenergy is possible, making use of the knowledge obtained in CenBio and other projects both in Norway and in other countries.

## Extended Life Cycle Assessment – WP4.1

Research activities in 2014 further examined the response of the carbon cycle-climate system to bioenergy production from forests and the inclusion of these findings into a life-cycle assessment perspective. The work specifically addressed both the role of $CO_2$ emissions and changes in biophysical surface properties (e.g., albedo) following harvest. Collaborations with leading institutions at an international level were a central part of this activity. NTNU is chairing the global

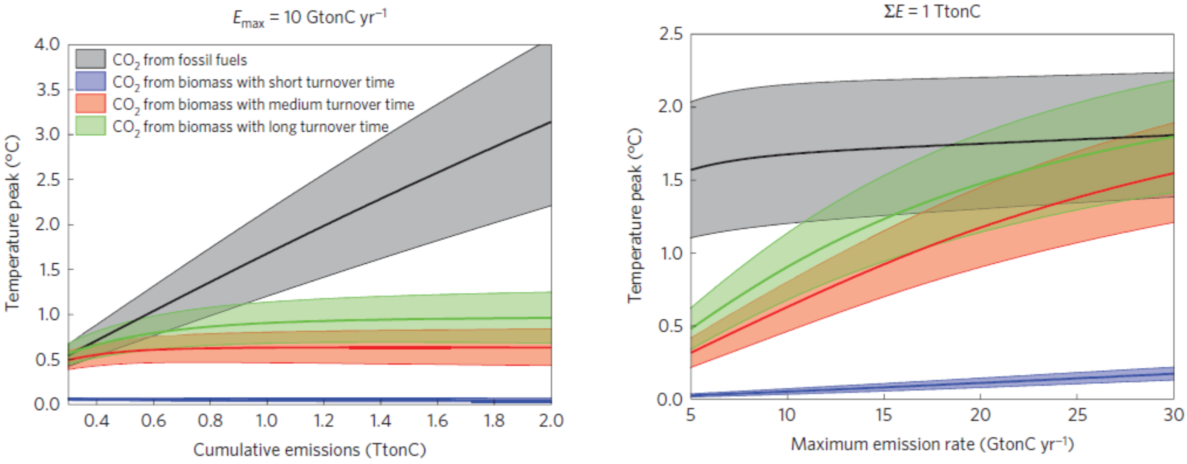


*Figure 23: Sensitivity of the temperature peak from idealised emission trajectories as a function of cumulative emissions (∑E) or maximum emission rates (Emax).*

warming task force of the UNEP-SETAC life-cycle initiative and is a member of IEA Bioenergy Task 38. A cooperation with IPCC carbon cycle experts lead to a publication in the top quality journal *Nature Climate Change*[21] that disentangles the role of bioenergy in the context of the 2 °C international policy target and in the related climate metric literature linking the temperature peak to cumulative emissions of long-lived GHGs or emission rates of shorter-lived species. The article shows the key diverging characteristics of the global mean temperature response to $CO_2$ emissions from bioenergy systems or fossil fuels. For instance, whereas the temperature peak from fossil $CO_2$ is proportional to the amount of cumulative emissions, the temperature peak from bioenergy $CO_2$ emissions is insensitive to the total amount of $CO_2$ emitted but it is rather constrained by the maximum rate at which emissions occur (see Figure 23).

## Ecosystem management – WP4.2

Intensified use of the forests as a feedstock source for bioenergy has to meet the requirement for ecological, social and economic sustainability. WP4.2 deals with short- and long-term ecological sustainability, largely at site scale.

The effects of forest harvesting for bioenergy on forest carbon stocks has been an area of controversy in recent years. A review paper[22] was submitted on the effects of intensified forest harvesting on soil organic carbon (SOC) (D4.2.13). The paper reviewed the findings in the scientific literature in order to evaluate the evidence for significant SOC losses following intensified biomass removal, especially whole-tree harvesting/thinning (WTH/WTT) vs. stem-only harvesting/thinning (SOH/SOT) (see Figure 24). There appears not to be sufficient field data available at present to draw firm conclusions about the long-term impact of intensified forest harvesting on SOC stocks in boreal and northern temperate forest ecosystems. Properly conducted long-term experiments are therefore necessary to enable us to clarify the relative importance of different harvesting practices on the SOC stores, and under which conditions the size of the removals becomes critical.

Therefore, there is an uncertainty gap between the scientific results and the need for practically useable management guidelines and other governance measures. This gap might be bridged by expert opinions given to authorities and certification bodies. Results suggest that sustainable use of the forests as a source of feedstock for bioenergy is possible, making use of the knowledge obtained in CenBio and other projects both in Norway and in other countries.

WP4.2 provided the following inputs to management guidelines in 2014 (D4.2.15). These inputs are in agreement with recommendations made in comparable countries.

- Remove slash at most once in the course of the rotation.
- Do not remove all slash - let at least 30 percent remain. If possible, let the needles fall off before the branches and tops are removed, by leaving them in piles over the summer before removal. Compensation fertilisation can be used if necessary.
- In steep terrain and on ground with poor carrying capacity there may be a substantial risk of terrain damage. This can lead to damage to the vegetation and to erosion. Slash harvesting involves extra driving and is often done in the autumn, when the ground is not frozen or snow-covered. One should therefore consider the terrain and carrying capacity in the selection of stands for slash removal. Caution during removal of piles/logging residues is important.

After slash removal and replanting, one should follow carefully the development of small spruce plants that that have been planted where the piles were previously. It appears that pine weevils gnaw a lot on the small plants here, perhaps because they are attracted by the smell of resin. Supplementary planting may be considered.

Further contributions to governance measures such as management guidelines, standards, criteria and indicators, and estimates of the environmental performance of biomass value chains are being prepared in the form of a report, to be finalised in 2015.

## Costs, markets, policies and integrated sustainability analyses – **WP4.3**

### A review study: Impacts of forest bioenergy and policies on the forest sector markets in Europe – what do we know?

The main political objectives of EU's renewable strategy are decreased use of fossil energy sources, reduced $CO_2$ emissions and increased energy self-sufficiency. Wood-based bioenergy plays an important role in this strategy and

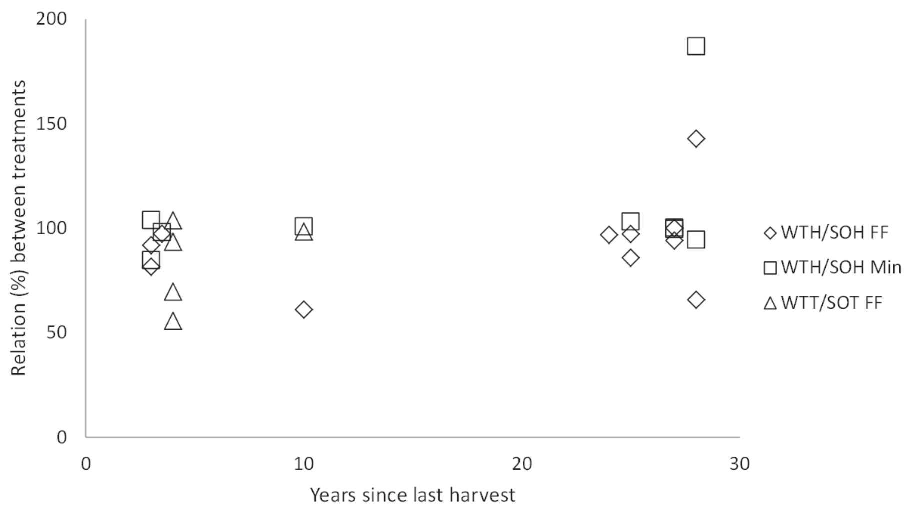


*Figure 24: Relative effect of harvest intensity on SOC. WTH/SOH (%) and WTT/SOT (%) in the forest floor (FF) and upper mineral soil (Min), based on the field studies. From Clarke et al. (submitted, 2014).*

the potential increase in wood demand for bioenergy production is of high interest for the EU forestry and forest industries due to its impacts on wood prices, profitability of forestry and forest industries, rural employment, recreation and forest ecology. In recent years, several studies have addressed the development of the wood demand for bioenergy, policies affecting it, and the above-mentioned impacts. In cooperation with the European Forest Institute, WP4.3 has led a review study[23], which gives a rather thorough review of five recent studies of these issues.

Major findings from the review are:

- Future utilization of forest biomass from EU may not be as large as it is often thought. In some cases, the forest biomass utilization for bioenergy purposes may not be very extensive even at high carbon price levels.

- The forest industry will continue to keep its important role as a producer and user of wood-based energy. This takes place despite the possible decline in consumption and production of some end products, like graphic papers, that is likely to decrease the production of pulp, which is also an important generator of bioenergy.

- A large share of the woody biomass going to energy production will also in the future consists of the side products of the forest industry, like bark, sawdust and black liquor.

- The supply of logging residues and stumps for bioenergy is strongly connected to the industrial wood harvests. The studies suggest that if the carbon price is assumed to be the only instrument spurring the use of woody biomass for energy, it needs to rise to quite a high level before the competition between forest industries and the energy sector over the forest biomass starts to affect the forest industry production.

- Uncertainty over future policies makes the business environment challenging for the investors.
  - The projections of future energy wood demand vary quite significantly between the studies. This indicates the high uncertainty that prevails over the future development of the use of energy wood. Perhaps the most important source for uncertainty is political. How will the carbon price develop in the future due to local or global climate policies and what type of taxes and subsidies will be implemented for wood bioenergy and alternative competing energy forms? Will future policy treat woody biomass used for energy production as carbon neutral or not? Do the possible sustainable biomass criteria effect woody biomass utilisation for energy?
  - Subsidies directed to one sector may harm the other sectors and they can also increase the costs of mitigating climate change.
  - It is vital that the policy makers are aware of the many impacts of the various policies, and have clear priorities guiding them to accept trade-offs between sometimes conflicting policy goals.

- Need for a synthesis study taking into account also the environmental sustainability.

*Results suggest that sustainable use of the forests as a source of feedstock for bioenergy is possible, making use of the knowledge obtained in CenBio and other projects both in Norway and in other countries.*

# Knowledge transfer and innovation **SP5**

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**Knowledge transfer and innovation SP5/NTNU**

| | |
|---|---|
| Bioenergy graduate school | WP5.1 |
| Knowledge transfer and dissemination | WP5.2 |
| Innovation management | WP5.3 |

**The main purposes of SP5 are:**

- **The development of educational structures to train the next generation of bioenergy researchers,**
- **To enhance the communication about CenBio activities both at scientific level, and to the general population,**
- **The management of the CenBio innovations to better support the development of the bioenergy industry.**

## Bio-Energy Graduate School – **WP5.1**

One of the major tasks for the Bio-Energy Graduate School is to promote studies in bioenergy. Now both NMBU and NTNU are running master courses in bioenergy on a regular basis based on an initiative from CenBio, as described in the Appendices. One master student performed their Master Thesis within CenBio activities in 2014 (see Table 14).

Approximately 25 PhD candidates have been affiliated with CenBio (see Table 12 and Table 13), and three more candidates have defended their thesis successfully in the last year. So far, joint PhD courses in bioenergy have not been developed. However, planning has started for a common course portfolio where also external courses will be advertised. This work will be extended in 2015, and aims to be sustainable also after the Center's project time. The level of the PhD candidates affiliated is sufficiently high so that they actively participate in CenBio's workshops as any other researcher.

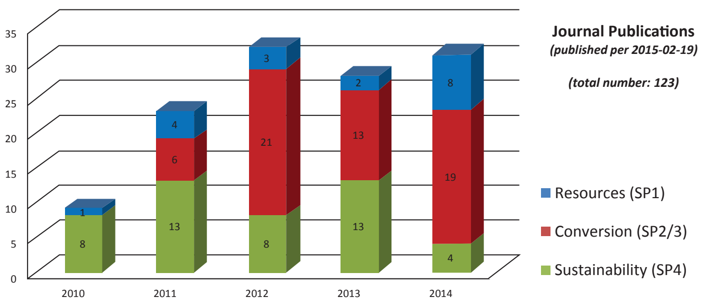


*Figure 25: Status of published peer-reviewed articles per year and per research activity.*

## Knowledge transfer and dissemination – WP5.2

### Deliverables

All results from both management and research activities within CenBio are documented in Deliverables, whether they are public or for internal distribution only. The list presented in the Appendices (see Table 24) shows the deliverables that were finalised in 2014.

One of the overall targets for CenBio is to deliver **150 international publications**, of which 75 in reputed peer-reviewed journals. Figure 30 shows the current status of the publications in peer-reviewed journals. The list of journal publications from 2014 is given in the Appendices (see Table 18).

In 2014, a large number of international conferences have been attended by the CenBio participants, as shown in the lists of conference papers and conference presentations in the Appendices (see Table 19 and Table 20).

CenBio researchers also appeared in the media, mainly in Norwegian newspapers, to raise awareness on some topical issues (wood stoves, biomass resources, etc.) or simply to popularize the topics of research tackled in CenBio. The list of media contributions is given in the Appendices (see Table 23).

### Website: www.CenBio.no

The first version of the CenBio website was established and published in June 2009. The website is regularly updated, especially with new public deliverables and news relevant to the Centre. A screenshot of the homepage is shown in Figure 28.

Publications, including peer-reviewed journal papers, conference papers, conference presenta-


*Figure 26: CenBio Researcher Michael Becidan was in December interviewed by a Franco-German TV network, ARTE. ARTE is a European culture and public service television channel. Becidan spoke about a waste-to-energy project in Oslo.* (Photo: Facsimile ARTE)


*Figure 27: Researcher Morten Seljeskog instructed the NRK viewers what NOT to put into your woodstove on the consumer affairs programme "Forbrukerinnspektørene" on 15. January 2014.* (Photo: Facsimile NRK)

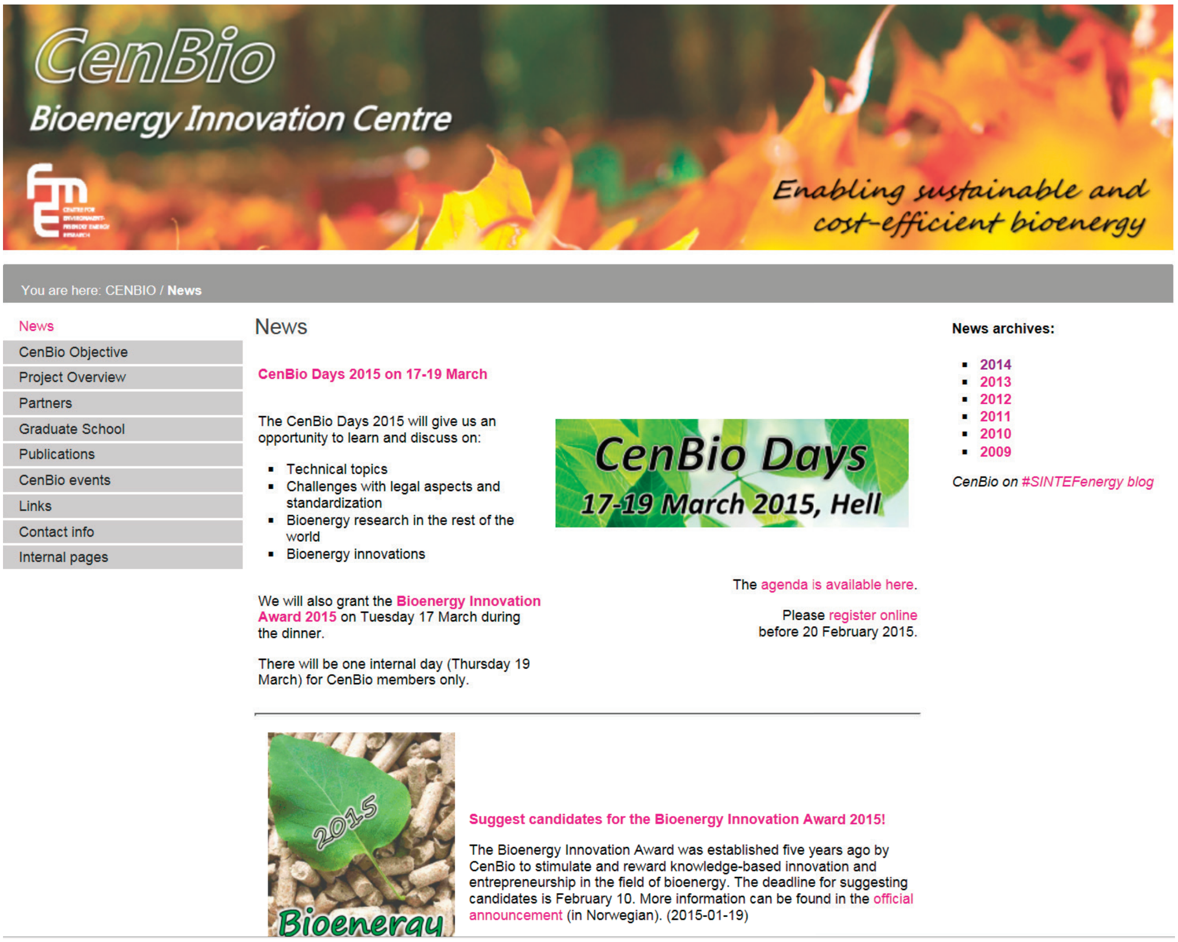


*Figure 28: CenBio homepage – www.CenBio.no (per 2015-02-10).*

tions, PhD thesis, chapters in book and media contribution are listed on the website. Web links have been implemented when the documents are publicly available online.

The page for contact information contains the coordinates of the Centre management, including SP leaders and WP leaders.

## Innovation Management – **WP5.3**

### The target is 25 completed innovations

New technological developments and innovations are crucial in order to reach the national goal of doubling the use of bioenergy within 2020. Innovation is an important part of the CenBio project with a quantified target of 25 completed innovations. The activities in this work package ensure that innovation is an integrated part of CenBio.

It was essential to establish a common understanding of innovation and how to implement the innovation activity in CenBio. This issue has been discussed in the three innovation workshops, which were arranged in 2010, 2011 and 2013. A CenBio definition of innovation has been approved, and innovation is included as a guiding star in the annual work plans.

The "List of innovations" (see Table 6) includes more than 30 potential innovations that are identified by now, and we are working systematically to develop these. In this context, patenting and publishing processes are an important issue that has been considered in a separate deliverable.

Nine innovations have so far been completed and fully implemented:

- Afterburner for woodstoves meeting the Norwegian environmental requirements, in close collaboration with the User partner Norsk Kleber AS.
- New test method for wood stoves. It is time-saving (25-50%) compared to existing methods and also cost-saving. This is highly relevant for the wood stoves User partners such as Jøtul AS.

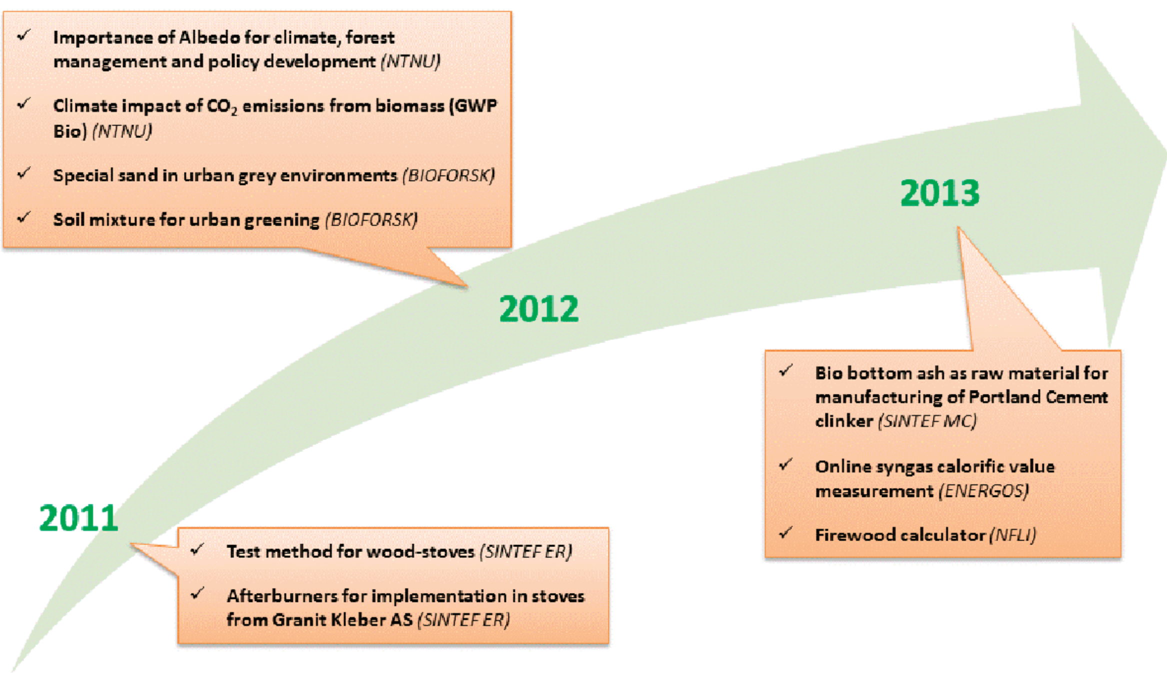


*Figure 29: CenBio innovations completed since the beginning of the Centre.*

- Knowledge developed on the importance of albedo for climate and forest management as well as policy development.
- Internationally- and UN-admitted demonstration that $CO_2$ from biomass has lower climate impact than from fossil fuels.
- Ash utilisation as a commercial product 1: Special sand designed to give no germination of weeds, licensed to Asak Miljøstein AS.
- Ash utilisation as a commercial product 2: Soil mixture for urban greening, based on ash from the User partner Akershus Energi AS, licensed to Herremyr Gård AS,
- Method for on-line syngas calorific value measurement that allows continuous monitoring is developed by Energos AS and equipment is installed at a commercial plant.
- Firewood calculator. A new method is developed that sets the price of firewood based on energy content which is the parameter of interest for the customer, instead of volume which has been the previous/current practice.
- Bio bottom ash as raw material for manufacturing of Portland Cement is a concept developed that will stretch the raw material resources (calcium carbonate) and reduce the cement plant $CO_2$ emissions.

Table 6: List of innovations within CenBio (per 31 December 2014).

| No | Title | RTD partner | Category of innovation | Status |
|---|---|---|---|---|
| I1.1.1 | *Biomass equations for Birch in Norway* | NFLI | Model | Nearly completed |
| I1.1.2 | *Biomass expansion factors for Spruce, Pine and Birch in Norway* | NFLI | Model | In progress |
| I1.2.1 | *Cost efficient harvesting and transportation* | NFLI | Technology | In progress |
| I1.2.2 | *Improved timbertrucks* | NFLI | Technology | Cancelled |
| I1.2.3 | *Improved grapple* | NFLI | Technology | Nearly completed |
| I1.2.4 | *Improved bucking procedures* | NFLI | Product | Not started |
| I1.2.5 | *Spreadsheet tool for strategic supply chain configuration* | NFLI | Concept | Nearly completed |
| I1.2.6 | *Trojan Chip Truck Chipper* | NFLI | Product | Not started |
| I1.3.1 | *Tailored fuel mixtures* | SINTEF-ER | Product | In progress |
| I1.3.2 | *Tailored chip deliveries* | NFLI | Concept | In progress |
| **I1.3.3** | ***Firewood calculator*** | **NFLI** | **Service** | **Completed** |
| I1.4.1 | *New fertilizers* | BIOFORSK | Product | In progress |
| I1.4.2 | *Organic NKP fertilizer* | BIOFORSK | Product | In progress |
| **I1.4.3** | ***Special sand*** | **BIOFORSK** | **Product** | **Completed** |
| **I1.4.4** | ***Soil mixture*** | **BIOFORSK** | **Product** | **Completed** |
| **I1.4.5** | ***Bio bottom ash as raw material for manufacturing of Portland Cement clinker*** | **SINTEF-MC** | **Concept** | **Completed** |
| I2.1.1 | *Additives and fuel mixing procedures* | SINTEF-ER | Concept | In progress |
| I2.1.2 | *Reduced emissions of NOx and particulate matter* | SINTEF-ER | Concept | In progress |
| I2.1.3 | *Smart fuels* | SINTEF-ER | Concept | In progress |
| I2.1.4 | *Instrumentation - temperature measurements* | SINTEF-ER | Technology | Not started |
| **I2.2.1** | ***On-line syngas calorific value measurement*** | **SINTEF-ER** | **Technology** | **Completed** |
| I2.3.1 | *Biocarbon production* | SINTEF-ER | Process | CenBio work completed |

| No | Title | RTD partner | Category of innovation | Status |
|---|---|---|---|---|
| 12.4.1 | *Increased energy yields from anaerobic digestion* | BIOFORSK | Subprocess | In progress |
| 13.1.1 | *Clean-burning stoves and fireplaces* | SINTEF-ER | Technology | In progress |
| **13.1.2** | ***Afterburners for implementation in stoves from Norsk Kleber AS*** | **SINTEF-ER** | **Component** | **Completed** |
| **13.1.3** | ***Test method for wood-stoves*** | **SINTEF-ER** | **Service** | **Completed** |
| 13.1.4 | *New measurement techniques* | SINTEF-ER | Service | In progress |
| 13.1.5 | *New and revised standards* | SINTEF-ER | Service | In progress |
| 13.2.1 | *Ultra-efficient district heating plants* | SINTEF-ER | New application | In progress |
| 13.2.2 | *Fossil C measurements* | SINTEF-ER | Technology | In progress |
| 13.3.1 | *CHP with 100% energy efficiency* | SINTEF-ER | Concept | In progress |
| 13.4.1 | *Low-emission plants* | SINTEF-ER | Concept | In progress |
| **14.1.1** | ***Albedo and forests*** | **NTNU** | **Concept** | **Completed** |
| **14.1.2** | ***Climate impact of $CO_2$ emissions from biomass (GWP bio)*** | **NTNU** | **Model** | **Completed** |
| 14.1.3 | *Short-lived vs. long-lived climate forcers* | NTNU | Concept | Nearly completed |
| 14.2.1 | *Recommendations for sustainable harvesting* | NFLI | New application | In progress |
| 14.2.2 | *Contribution to development of international standards* | NFLI | New application | In progress |
| 14.2.3 | *Environmental performance for biomass value chains* | NFLI | New application | In progress |
| 14.2.4 | *Criteria and Indicators for sustainable bioenergy* | NFLI | New application | In progress |
| 14.3 1 | *Global model development* | NMBU | Model | In progress |
| 14.3.2 | *National forest sector model for Norway* | NMBU | Model | In progress |

Another four innovations are nearly completed and are expected to be finalised in 2015.

## Bioenergy Innovation Awards

CenBio has introduced the "Bioenergy Innovation Award" (BIA), a nationally-advertised innovation award within stationary bioenergy. This award was established to stimulate and reward knowledge based innovation and entrepreneurship, and to contribute to identify projects with innovation potential as well as enhance the focus on innovative thinking and activities within the bioenergy field. Bioenergy Innovation Award also contributes to put the focus on innovation-driven activities in CenBio and stimulates the enthusiasm to explore and realize new ideas.

In 2011, the first BIA awarded SINTEF Research Scientist Edvard Karlsvik for his innovative work with combustion technology for residential woodstoves. In 2012, the second BIA awarded Cambi AS, one of the CenBio partners, for their innovative biogas production process for biomass from waste and sewerage, which is implemented in many plants world-wide. The winner in 2013 was Sølor Bioenergi, exclusively using contaminated timber as energy source in their 10 MW combined heat and power (CHP) plant.

The BIA 2014 was awarded 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. These solutions have been implemented and are currently being used in the day-to-day operation by the three forest owners' cooperative. The ALLMA system contributes to a more efficient work and ensures an optimal exploitation of Norwegian forest resources.

CenBio has a fruitful cooperation with FME CenSES (Centre for Sustainable Energy Studies) including their actively involvement in the CenBio workshops as well as CenSES Master and PhD students studying the interaction between the research and User partners in the FME. Based on the results from this work, the emphasis on how to increase the value-creation for the User partners, based on CenBio results, has been intensified.

*Figure 30: Left: Rune Volla (right) presents the winner of the BIA 2014 Mjøsen Skog represented by Erik A. Dahl (left). Right: Rune Volla, Berta Matas Güell, and Odd Jarle Skjelhaugen surround the winner Erik A. Dahl.*

# Value chain assessment **SP6**


**Anders Hammer Strømman**
***Leader of Value Chain Assessment***

NTNU – Norwegian University of Science and Technology


**Value chain assessment SP6/NTNU**

| | |
|---|---|
| Environment and cost characteristics | WP6.1 |

**SP6 aims at integrating a wide array of expertise and knowledge matured within CenBio along with detailed datasets generated from the other SPs into a holistic environmental and economic assessment of bioenergy value chains. This goal requires a thorough and detailed assessment of the existing bioenergy chains as well as of the possible future options. This research is essential to provide sustainable directions for the national goal of doubling bioenergy production by the year 2020.**

The specific objective of SP6 is to identify the portfolio of individual value chains that will enable a sustainable increase of bioenergy utilisation in Norway. This task entails the following four sub objectives:

- Identification of the environmental and economic characteristics of current individual Norwegian bioenergy value chains (individual performance).
- Identification of the total overall environmental and economic characteristics of the current Norwegian bioenergy system (total performance).
- Identification of the environmental and economic characteristics of prospective novel individual Norwegian bioenergy value chains (individual performance).
- Identification of the total overall environmental and economic characteristics of alternative scenarios for different prospective Norwegian bioenergy systems (total performance).

Several meetings have been carried out with all partners to ensure the maximum level of interaction and cooperation within SP6. The value chains concept can certainly be seen as a combination of many research activities from CenBio.

In 2014, the SP6 team has been working on a Norwegian system level as well as along each single value chains. On system level, an extensive list of all the existing biomass to energy (BtE) plants, waste-to-energy plants (WtE) and biogas plants has been created. The list entails more than 700 plants. In addition, a comprehensive Sankey diagram where the overall biomass and waste flows going to the different bioenergy conversion plants are mapped. On a value chain level, the SP6 team has focus on a total of 30 value chains, grouped by fuel type.

*The holistic approach used by the SP6 team enabled to highlight hot-spots in the different value chains.*

## Main activities performed by NTNU on the environmental assessment of bioenergy chains

Lots of efforts have been put into CenBio's last born SP6 in 2014. The aim of SP6 is to map and integrate the wide arrays of expertise and knowledge that have matured in CenBio in order to give a holistic environmental assessment of the individual bioenergy value chains. This task could be compared with the assembly of Legos of different sizes and colors in a comprehensive and robust way in order to build various single houses.

Two approaches have been used. The first one is a top-down approach, on a system level while the second one is a bottom-up approach, on a bioenergy conversion plant level. In the former approach, the overall flows of biomass going to the different bioenergy recovery plants have been mapped and presented in a comprehensive Sankey diagram. In the latter approach, the concept of value chains has been used. The value chains

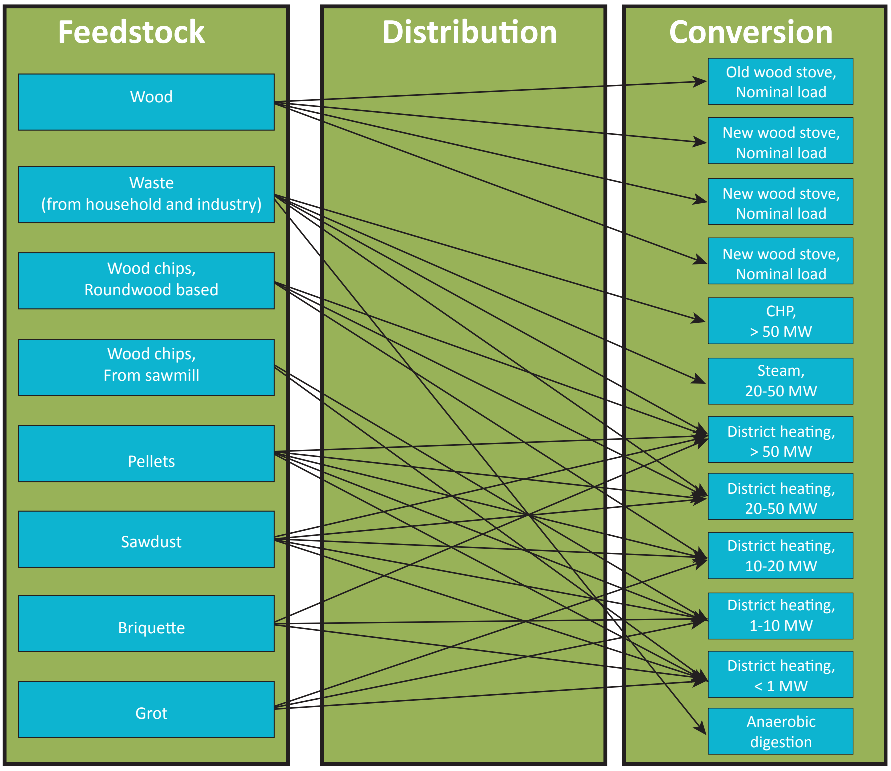


*Figure 31: Overall structure of the value chains as seen in CenBio SP6.*

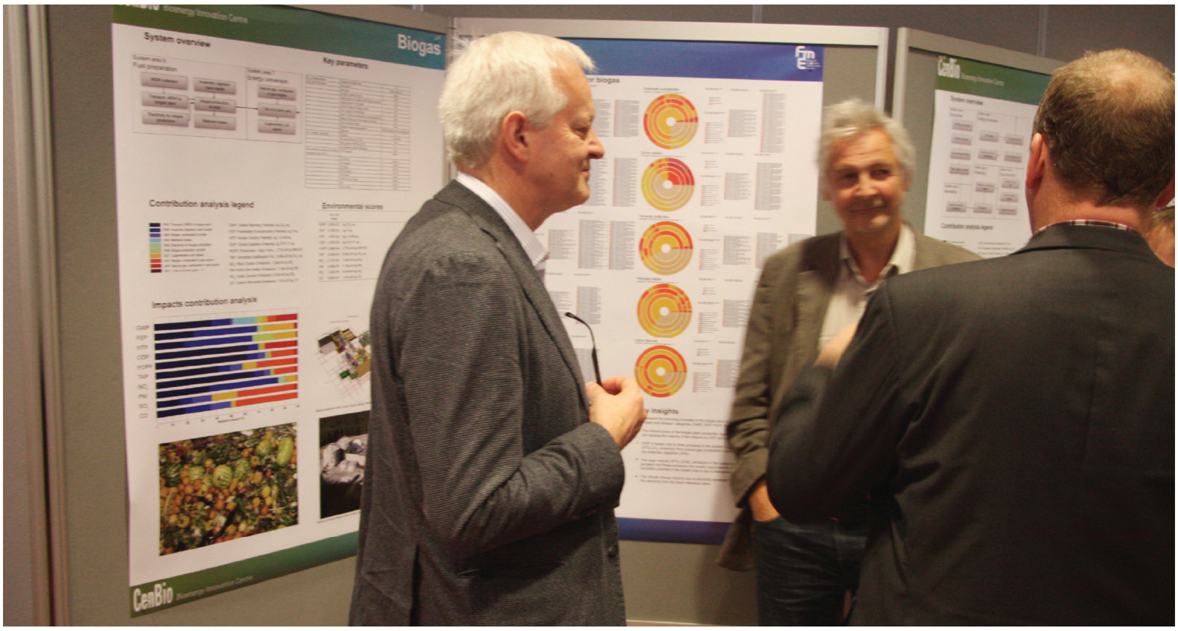


*Figure 32: Picture taken at the SP6 poster session, CenBio Strategic Days (Gardermoen, 29–30 October 2014)* *(Photo: Odd Jarle Skjelhaugen)*

have been further divided into eight subgroups, based on fuel type. The eight fuel type consists of wood, waste, woodchips (round wood based), woodchips (from sawmill), pellets, sawdust, briquette and GROT. The overall structure of the value chains can be seen in Figure 31.

Preliminary results have been presented during the CenBio Strategic Days in Autumn 2014 (see Figure 32). The holistic approach used by the SP6 team enabled to highlight hot-spots in the different value chains. For example, the transport of the biomass to the end-user or bioenergy conversion plant is of importance, this for most of the value chains. The vast majority of human toxicity potential is not occurring at the waste-to-energy plant, but is due to heavy metals leaching into ground water at the bottom-ash and fly-ash handling landfill site. A substantial part of the Global Warming Potential impact across all the cases with storage of comminuted fuel is due to the biomass storage and the associated off-gassing of methane and nitrous oxide emissions.

The models used in 2014 to generate preliminary results will be revised and further calibrate in 2015 to best represent Norwegian conditions.

Main activities performed by NMBU on the economic assessment of bioenergy chains

- Use of levelised cost of energy (LCOE) as a metric for the economic assessments of the different links in the value chains, as well as for the entire value chains in SP6;
- Estimation of LCOE based on the present value of total life-cycle cost (TLCC);
- Estimation of LCOE both in a social and in a firm perspective;
- Development of integrated indicators describing cost-effectiveness of different bioenergy chains;
- Estimation of different environmental metrics (indicators) for the value chains and their elements;
- Development of a framework for ranking the different value chains forming a basis in support of policy and decision.

### Main activities performed by SINTEF Energy Research on CHP/District Heating

- Appropriate process flow diagrams have been made, pointing out main differences between plant categories.
- Taking into account direct feedback from the industry, a plant survey form was elaborated and sent out to the User partners in 2013. The requested information encompassed several plant specific information and data (e.g., size and location of the plant, production, emissions, costs, fuel type, consumables etc.). The focus in 2014 was on the following-up of the survey.
- Based on information collected in the survey, mass and energy balances have been performed (plant process models).
- The initial plant process models have resulted in calculations on the thermal conversion, heat recovery steam generation, district heat and power production, and flue gas cleaning/emissions.
- Delivery of the database with information on Norwegian waste and biomass conversion plants.

### Summary of the activities performed by SINTEF Energy Research on wood stoves

- Combustion of wood logs in wood stoves is an important biomass consumer and emission source in Norway. A previous study has estimated the contribution of different emissions from wood stoves to selected environmental and health impact categories. The results from this work also show the importance of having specific/representative emission factors for different emission compounds from wood stoves, both traditional (old technology pre-1998) and modern wood stoves.
- The CenBio SP6 work on wood stoves concentrated on emission factors, with the aim of checking the validity of the existing emission factors used in the Norwegian national emission inventory. The main goal is to perform experimental analysis and literature review to either confirm the existing emission factors or suggest improved factors that are more representative for the current Norwegian firing habits.
- So far, the conclusion is that there is a need for updating some of the emission factors, an update that can significantly change the relative contribution of different emission compounds to different environmental and health impact categories and their relative importance.
- In addition, wood stove efficiencies have been evaluated, showing that particularly for traditional (old technology) wood stoves, there is a need for increasing the efficiency currently used. This work was finalized in 2014, also collecting materials and costs data needed for a complete value chain analysis of the wood stove segment in Norway.

The results from SP6 activities in 2014 were mainly reported as internal documents. One major document from SP6 is a database of existing district heating and combined heat and power plants in Norway using waste and wood-derived biomass. The information contained in the plants database includes main system design data, mass and energy balances, costs and emission data; in most cases based on information from CenBio User partners. Such plants data served as input for the Life Cycle Analysis (LCA) models of the overall Norwegian waste-to-energy and biomass-to-energy systems. Preliminary results from the LCA analysis were presented in the form of a set of posters for various bioenergy value chains at the CenBio Strategic Days in October. An additional internal technical report was produced on the costing of biomass heat and CHP production.

# International cooperation

*Most national and international cooperations for each SP and WP are directly mentioned through the description of the activities for each SP and WP.*

The international collaboration in CenBio takes place at different levels: (1) direct involvement of international partners in the R&D activities conducted in the Centre, particularly with our Swedish research and User partner Vattenfall, (2) through international publications and participation in international conferences, (3) through visiting researchers to/from CenBio, and (4) through international researchers' networks. Some highlights regarding these four levels of collaboration are reported below.

- Since the start of CenBio in 2009, the **international partner Vattenfall**, through both their R&D unit and biomass plant operative unit, has made important contributions to the CenBio research efforts on combined heat and power (CHP) production from biomass, with focus on challenging biomass, especially demolition wood. Many operational challenges may arise when using challenging biomass fuels, both regarding emissions (e.g., $NO_x$) and ash related aspects (e.g., corrosion on superheaters). The Vattenfall studies have been important and complementary to other CenBio activities. The work conducted on the Vattenfall ChlorOut technology for combined $NO_x$ and corrosion reduction is highly relevant for the Centre. It is a promising technology that Vattenfall can continuously test and optimise in their own plants. As such, Vattenfall brings unique capabilities into CenBio that strengthen the Centre, while interacting with CenBio researchers on generic issues with the aim of optimum utilisation of challenging biomass fuels in CHP plants.

- CenBio has been presented at a number of **international conferences** in 2014. Details are listed in Table 20.

- The total number of **international collaborations** resulting in journal publications and peer-reviewed conference papers funded by CenBio is 72 per February 2015, an ambitious number very close the initial Centre target (75 by 2016). Figure 33 shows the status of journal publications resulting from collaborative work involving non-CenBio partners, since the start of the Centre. Among them, two journal papers have been published within the last months and should be mentioned. The first one, entitled *"Steam explosion pretreatment for enhancing biogas production of late harvested hay"*, has been published in *Bioresource Technology*. NMBU and Cambi AS took part as co-authors in this collaboration with University of Natural Resources and Life Sciences (Austria), AlpS-GmbH (Austria) and University of Napoli (Italy). This example represents a trend that the Centre is putting efforts on, namely improve industry's involvement through joint publications with the R&D partners. The second one, entitled *"Linearity between temperature peak and bioenergy $CO_2$ emission rates"*, has been published in *Nature Climate Change*, which has a very high global standing. Francesco Cherubini (NTNU) is first author in this collaboration with the French research centres CNRS-PontsParisTech-EHESS-AgroParisTech-CIRAD and CEA-CNRS-UVSQ.

- CenBio has welcomed **9 visiting researchers** in total, including 4 in 2014 (see Table 9). Some of those researchers come on a regular basis every year. For instance, the fruitful cooperation with Professor Michael J. Antal, Jr. from University of Hawaii has continued in 2014, with a focus on pyrolysis.

- **6 CenBio researchers in total have visited other countries** for at least one month, including one in 2014 (see Table 10). All of them are PhD students and efforts are made to encourage researchers to take part in such exchanges.

- CenBio is funding **active participation in international researchers' networks**, such as EERA Bioenergy Joint Programme (BJP), IEA (e.g., Tasks 32, 36, 37, 38, 40 and 43) and COST Actions in order to position Norway, and in particular main bioenergy-based activities, central both at European and international levels. A few highlights are listed below:

  - In EERA BJP, SINTEF-ER (Michael Becidan) is coordinator for "Stationary bioenergy" and leads task force meetings with research partners from all over Europe to achieve the network's target to contribute to an acceleration of the development of next generation conversion and upgrading technologies.

  - In IEA Task 32 – *Biomass combustion and co-firing*, led by Jaap Koppejan (Procede Biomass BV, The Netherlands), SINTEF-ER is an active contributor. Task 32 covers all scales of biomass combustion units for heat and combined heat and power production, in addition to co-firing of biomass in coal fired plants.

  - In IEA Task 36 – *Integrating energy recovery into solid waste management systems*, led by Dr Pat Howes (Ricardo-AEA - UK), SINTEF-ER is an active contributor. Their leader will join the Centre as a member of the CenBio Advisory Board and join the upcoming CenBio Days (17-19 March 2015) to get acquainted with the Centre.

  - In IEA Task 37 – *Energy from biogas and landfill gas*, Bioforsk represents CenBio through their activities on anaerobic digestion. Task 37 covers the biological treatment of the organic fraction of municipal solid waste as well as the anaerobic treatment of organic rich industrial waste water.

  - In IEA Task 43 – *Biomass feedstocks for energy markets*, NFLI plays an active role to realize the goals of the task force to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere.

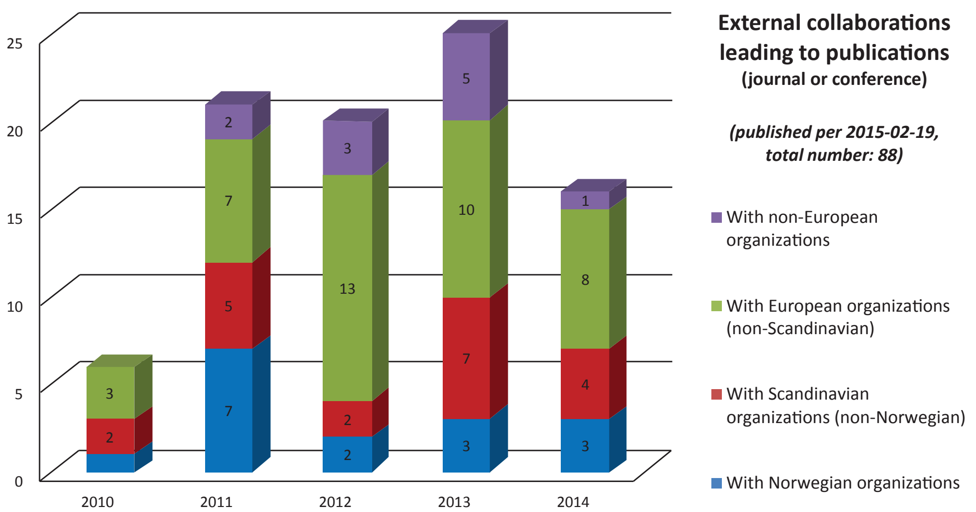


*Figure 33: Status of external collaborations resulting in journal publications within CenBio.*

## International institutions

The international institutions listed below took part in collaborative research activities with CenBio leading to publications in 2014:

- AlpS-GmbH (Austria)
- University of Natural Resources and Life Sciences (Austria)
- Technical University of Denmark (DK)
- University of Copenhagen (DK)
- Finnish Geodetic institute (FI)
- Finnish Environment institute (FI)
- Tampere university of technology (FI)
- CNRS-PontsParisTech-EHESS-AgroParis-Tech-CIRAD (FR)
- CEA-CNRS-UVSQ (FR)
- Hungarian Academy of Sciences (HU)
- Coillte - Irish Forestry Board (IR)
- University of Napoli (IT)
- Wageningen Univ and Research Centre (NE)
- Mälardalens University (SE)
- Skogforsk (SE)
- Swedish Institute of Agricultural and Environmental Engineering (SE)
- Swedish University of Agricultural Sciences (SE)
- Newcastle University (UK)
- Norwich research park (UK)

## Participation in Tasks from the International Energy Agency (IEA)

Various IEA Bioenergy tasks with involvement of CenBio staff are listed in Table 8.

Table 7: Participation in IEA Bioenergy activities.

| IEA Bioenergy Task # | Task title | Task member WP # | Representative |
|---|---|---|---|
| Task 32 | *Biomass Combustion and Co-firing* | SINTEF-ER WP2.1 | Øyvind Skreiberg |
| Task 33 | *Thermal Gasification of Biomass* | SINTEF-ER WP2.2 | Roger A. Khalil |
| Task 36 | *Integrating Energy Recovery into Solid Waste Management Systems* | SINTEF-ER WP3.2 | Michaël Becidan |
| Task 37 | *Energy from biogas and landfill gas* | BIOFORSK WP2.4 | Espen Govasmark/ Roald Sørheim |
| Task 38 | *Greenhouse gas balances of biomass and bioenergy systems* | NMBU + NTNU SP4 | Anders Strømman |
| Task 40 | *Sustainable International Bioenergy Trade - Securing Supply and Demand* | NMBU WP4.3 | Birger Solberg<br>Erik Trømborg |
| Task 43 | *Biomass feedstocks for energy markets* | NFLI WP1.1 | Simen Gjølsjø |

# Recruitment

The research within CenBio is mainly performed by permanent employees with the research institutes and the universities (see Table 8). In some cases, doctoral and postdoctoral researchers have been recruited to perform research within CenBio. A list of such researchers is given in Tables 9–11.

# Appendices

## A. Personnel

### Key Researchers

Table 8: Key staff members who spent more than 10% of their time in CenBio in 2014.

| Name | Affiliation | Univ. degree | Sex | Position within own organisation | % of full time |
|---|---|---|---|---|---|
| Odd Jarle Skjelhaugen | NMBU | PhD | M | *Centre Director, Professor* | 30 % |
| Tron Haakon Eid | NMBU | PhD | M | *Professor* | 10 % |
| Even Bergseng | NMBU | PhD | M | *Research Scientist* | 15 % |
| Svein Jarle Horn | NMBU | PhD | M | *Professor* | 30 % |
| Olav Høibo | NMBU | PhD | M | *Professor* | 10 % |
| Øystein Johnsen | NMBU | PhD | M | *Dean of University* | 10 % |
| Andreas Brunner | NMBU | PhD | M | *Research Scientist* | 15 % |
| Shuling Chen Lillemo | NMBU | PhD | F | *Research Scientist* | 20 % |
| Vincent Eijsink | NMBU | PhD | M | *Research Scientist* | 10 % |
| Per Kristian Rørstad | NMBU | PhD | M | *Research Scientist* | 25 % |
| Birger Solberg | NMBU | PhD | M | *Professor* | 10 % |
| Mette Bugge | SINTEF-ER | MSc | F | *Research Scientist* | 20 % |
| Per Carlsson | SINTEF-ER | PhD | M | *Research Scientist* | 15 % |
| Nils Erland | SINTEF-ER | PhD | M | *Research Scientist* | 15 % |
| Berta Matas Güell | SINTEF-ER | PhD | F | *Research Manager* | 20 % |
| Einar Jordanger | SINTEF-ER | MSc | M | *Project Manager* | 50 % |
| Alexis Sevault | SINTEF-ER | PhD | M | *Research Scientist* | 50 % |
| Øyvind Skreiberg | SINTEF-ER | PhD | M | *Chief Research Scientist* | 25 % |
| Morten Seljeskog | SINTEF-ER | PhD | M | *Research Scientist* | 10 % |
| Line Rydså | SINTEF-ER | MSc | F | *Research Scientist* | 25 % |
| Michaël Becidan | SINTEF-ER | PhD | M | *Senior Research Scientist* | 30 % |
| Judit Sandquist | SINTEF-ER | PhD | F | *Research Scientist* | 20 % |
| Liang Wang | SINTEF-ER | PhD | M | *Research Scientist* | 60 % |
| Franziska Goile | SINTEF-ER | MSc | F | *Research Scientist* | 30 % |
| Anders H. Strømman | NTNU | PhD | M | *Professor* | 20 % |
| Terese Løvås | NTNU | PhD | F | *Professor* | 10 % |
| Francesco Cherubini | NTNU | PhD | M | *Research Scientist* | 100 % |
| Carine Grossrieder | NTNU | PhD | F | *Research Scientist* | 100 % |

| Name | Affiliation | Univ. degree | Sex | Position within own organization | % of full time |
|---|---|---|---|---|---|
| Trond K. Haraldsen | Bioforsk | PhD | M | *Senior Research Scientist* | 25 % |
| Roald Sørheim | Bioforsk | PhD | M | *Research Scientist* | 15 % |
| Uno Andersen | Bioforsk | MSc | M | *Research Scientist* | 10 % |
| Nicholas Clarke | NFLI | PhD | M | *Senior Research Scientist* | 10 % |
| Toril D. Eldhuset | NFLI | PhD | F | *Senior Research Scientist* | 20 % |
| Leif Kjøstelsen | NFLI | MSc | M | *Research Scientist* | 10 % |
| Helmer Belbo | NFLI | PhD | M | *Research Scientist* | 20 % |
| Eirik Nordhagen | NFLI | MSc | M | *Research Scientist* | 10 % |
| Janka Dibdiakova | NFLI | PhD | F | *Research Scientist* | 20 % |
| Simen Gjølsjø | NFLI | MSc | M | *Senior Adviser* | 20 % |
| Rasmus Astrup | NFLI | PhD | M | *Research Director* | 20 % |
| Bruce Talbot | NFLI | PhD | M | *Research Scientist* | 20 % |
| Bjarte Arne Øye | SINTEF-MC | PhD | M | *Research Scientist* | 20 % |
| Håkon Kassman | VRD | MSc | M | *Research Scientist* | 10 % |
| Åsa Astervik | VRD | MSc | F | *Research Scientist* | 10 % |

## Visiting Researchers

Table 9: Visiting researchers from other countries in 2014.

| Name | Position | Organisation | Country | Duration of stay |
|---|---|---|---|---|
| Michael J. Antal, Jr | *Professor* | University of Hawaii at Manoa | USA | 1 week/year (2009-2013); 5 weeks in 2014 |
| Alan Kerstein | *Independent Research Scientist* | Former Sandia National Laboratories | USA | 3 months/yr – (2012-2014) |
| Gabor Varhegyi | *Professor* | Hungarian Academy of Science | Hungary | 1 week in 2014 |
| Martina Boschiero | *Professor* | Free University of Bozen-Bolzano | Italy | 3 months in 2014 |

## CenBio researchers in research exchange abroad

Table 10: CenBio researchers in research exchange abroad in 2014

| Name | Position | Organisation | Country | Duration of stay |
|---|---|---|---|---|
| Eva Brod | PhD student | NMBU | Switzerland | 2014: 6 months |

## Postdoctoral Researchers

Table 11: List of postdoctoral researchers working in the Centre in 2014.

| Name | Affiliation | Source of funding | Sex | Nationality | Period worked in the Centre |
|---|---|---|---|---|---|
| Xiaoke Ku | NTNU | CenBio | M | Chinese | 2012 – 2015 |

## PhD students

A database on PhD students working on issues related to CenBio's research activities has been established; see Table 12 and Table 13.

Table 12: PhD students, both CenBio-funded and associated, working within CenBio in 2014.

| Name | Sex | Affil. | Topic/Research area | Source of funding | Period in the Centre |
|---|---|---|---|---|---|
| Paulo Borges | M | NMBU | *Develop decision support systems for long-term analyses of biomass* | CenBio WP1.1 | 2010-11 2014-02 |
| Geoffrey Guest | M | NTNU | *Hybrid life cycle analysis of solid bio-fuel systems* | CenBio WP4.1 | 2009-08 2014-01 |
| Dmitry Lysenko | M | NTNU | *Combustion modelling* | CenBio WP2.1 | 2010-03 2014-03 |
| Tuva Grytli | F | NTNU | *Value Chain assessment of bioenergy* | CenBio WP6.1 | 2013-12 2016-12 |
| Dhruv Tapasvi | M | NTNU | *Experimental studies on biomass torrefaction and gasification* | CenBio WP2.1 | 2010-01 2014-06 |
| Aaron Smith | M | NMBU/ NFLI | *Develop models and methods for quantification of birch biomass* | CenBio WP1.1/ RCN | 2010-08 2014-07 |
| Eva Brod | F | NMBU/ Bioforsk | *Organic waste resources and wood ash as fertiliser, phosphorus flows and stocks in the food system* | 50% CenBio / RCN | 2012-05 2016-04 |
| Quang Vu Bach | M | NTNU | *Thermal pre-treatment of bio-mass and biomass residues* | 20% CenBio / STOP | 2011-08 2015-01 |
| Silje Skår | F | NMBU | *Ecological modelling related to increased biomass removal in forests in Norway* | 25% CenBio / RCN | 2009-12 2014-12 |
| Kolbeinn Kristjansson | M | NTNU | *Stable heat release from batch combustion of wood* | StableWood (KPN Project) | 2012-03 2015-03 |

Table 13: Completed PhD theses linked to the Centre (per 2015-02-28).

| Year | Name | Sex | Title of thesis | Adviser | Institution granting degree |
|---|---|---|---|---|---|
| 2011 | Hanne K. Sjølie | F | *Analyses of the use of the Norwegian for-est sector in climate change mitigation* | Birger Solberg | NMBU |
| 2011 | Ryan Bright | M | *Environmental Systems Analysis of Road Transportation Based on Boreal Forest Biofuel: Case Studies and Scenarios for Nordic Europe* | Anders H. Strømman | NTNU |
| 2011 | Kavitha Pathmanathan | F | *Granular-bed Filtration Assisted by Filter Cake Formation: Advanced Design and Experimental Verification* | Johan E. Hustad | NTNU |

| Year | Name | Sex | Title of thesis | Adviser | Institution granting degree |
|---|---|---|---|---|---|
| 2011 | Helmer Belbo | M | *Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees* | Rolf Björheden | Linnaeus University, Sweden |
| 2012 | Tore S. Filbakk | M | *Fuel quality of forest biomass intended for chips and pellets: the influence of raw material characteristics, storage and handling* | Olav Høibø | NMBU |
| 2012 | Dhandapani Kannan | M | *Study of Second Generation Biofuels in Internal Combustion Engines* | Johan E. Hustad | NTNU |
| 2012 | Ehsan Houshfar | M | *Experimental and numerical studies on two-stage combustion of biomass* | Terese Løvås | NTNU |
| 2012 | Liang Wang | M | *Effect of Additives in Reducing Ash Sintering and Slagging in Biomass Combustion Applications* | Johan E. Hustad | NTNU |
| 2013 | Maria M. Estevez | F | *Improving the anaerobic digestion of lignocelluloses and organic wastes: effects of steam explosion, co-digestion and digestate recirculation* | John Morken | NMBU |
| 2013 | Shuling Chen Lillemo | F | *Consumers and bioenergy: the effects of behavioural factors on households' heating consumption choice in Norway* | Mette Vik | NMBU |
| 2013 | Geir Skjevrak | M | *Wood pellets utilized in the commercial and residential sectors – an in-depth study of selected barriers for increased use* | Johan Einar Hustad | NTNU |
| 2014 | Geoffrey Guest | M | *The climate change impacts from bio-genic carbon in products across time* | Anders H. Strømman | NTNU |
| 2014 | Dmitry Lysenko | M | *On numerical simulation of turbulent flows and combustion* | Ivar S. Ertesvåg | NTNU |
| 2014 | Paulo Jorge de Almeida Borges | M | *Improved models and methods for solving temporal and spatial harvest activities in forest planning* | Tron Eid | NMBU |
| 2015 | Quang Vu Bach | M | *Wet Torrefaction of Biomass - Production and Conversation of Hydrochar* | Khanh-Quang Tran | NTNU |

### Master degrees

Both NTNU and NMBU were providing courses on Bioenergy at Master level in 2014. Some details about the master's level courses in place in 2014 are given below:

| **Course:** | **NTNU – TEP4270: Bioenergy** |
|---|---|
| **Level:** | Master, 7.5 credits |
| **Objective:** | After the course the students will be able to work with cross-cutting problems and planning processes linked to bioenergy projects. |
| **Frequency:** | Annually, Fall term. |
| **Students:** | 37 students in Autumn 2014 |
| **Activities:** | Class lectures with four sets of home exercises, combined with one thermal lab and several training sessions on process simulation to support the term paper dealing with bioenergy system analysis. |

| **Course:** | **NMBU – FORN310: Bioenergy – Resources, Profitability and Solutions** |
|---|---|
| **Level:** | Master, 5.0 credits |
| **Objective:** | The course should provide an in-depth understanding of the economics of bioenergy use and impacts on the carbon cycle and climate of bioenergy production. In addition, the course should provide insights in technologies for bioenergy production. |
| **Frequency:** | Annually, last one in spring 2014. |
| **Activities:** | Class lectures with sets of home exercises, combined with independent study. |

| **Course:** | **NMBU – SKOG310: Nordic Forestry and Forest Research** |
|---|---|
| **Level:** | Master, 10.0 credits |
| **Objective:** | This course is designed for exchange students from outside Norway wishing to learn about forestry and forest research in Norway and the other Nordic countries. Students will learn about:<br>- The natural and socio-economic conditions for forestry in the Nordic countries and the forestry practices that are special to that region;<br>- Current research results related to forest management from NMBU and other Nordic forest research institutes. |
| **Frequency:** | Even years, last one in autumn 2014. |
| **Activities:** | Short lectures to introduce the students to natural and socio-economic conditions for forest management in Norway and the other Nordic countries. Research papers within seven general topics, where INA contributes actively to forest research, are discussed in seminars with the teachers. |

Table 14: M.Sc. thesis in the Centre in 2014.

| Name | Sex | Title of thesis | Adviser | Institution |
|---|---|---|---|---|
| Tiril Jeanette Seldal | F | *Life Cycle Assessment of Biogas/Biofuel Production from Organic Waste* | Anders H. Strømman | NTNU |

## B. Accountancy

A detailed accounts report for 2014 was submitted to RCN in January 2015. The main financial figures are repeated in this annual report.

### Budget

Table 15 shows the anticipated overall budget for CenBio over eight years. The total costs are estimated at NOK 267.205 million, distributed as given in the table.

The total funding from RCN is NOK 120 million for the project period, i.e. NOK 15 million per year. Since CenBio started 1 March 2009, the budget for 2009 was somewhat reduced compared to an average year. The cost budget for 2014 was NOK 30.733 million, while the final reported costs for 2014 added up to NOK 32.355 million.

Table 15: CenBio overall budget.

| (MNOK) | Actual | Actual | Actual | Actual | Actual | Actual | Budget | Plan | |
|---|---|---|---|---|---|---|---|---|---|
| Total | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
| 267.205 | 27.738 | 38.594 | 39.291 | 38.012 | 30.072 | 32.355 | 30.295 | 30.295 | 0.552 |

### Accounts 2014

Total costs reported from the partners in 2014 amounts to NOK 32.355 million, of which NOK 28.7 million from Research partners and NOK 3.7 million from corporate partners. The funding from RCN amounts to 46% of the total costs.

### Funding

Table 16: Funding from various sources 2014.

| Source | NOK million |
|---|---|
| The Research Council | 15.000 |
| Research partners | 7.970 |
| User partners | 9.385 |
| Public partners | 0 |
| **Total** | **32.355** |

### Costs

Table 17: Reported costs from various partners 2014.

| Type | NOK million |
|---|---|
| Research partners | 28.668 |
| User partners | 3.687 |
| Public partners | 0 |
| Equipment | 0 |
| **Total** | **32.355** |

# C. Publications

## Journal Papers

Table 18: List of journal papers published in 2014.

| Title | Author(s) | Lead Partner(s) | Journal |
|---|---|---|---|
| *Applying simulated annealing using different methods for the neighborhood search in forest planning problems* | Paulo Borges, Tron Eid, Even Bergseng | NMBU | European Journal of Operational Research |
| *Adjacency constraints in forestry - a simulated annealing approach comparing different candidate solution generators* | Paulo Jorge de Almeida Borges, Even Bergseng, Tron Eid | NMBU | Mathematical and Computational Forestry & Natural-Resource Sciences |
| *Tree root system characterization and volume estimation by terrestrial laser scanning and quantitative structure modelling* | A Smith, R Astrup, P Raumonen, J Liski, A Krooks, S Kaasalainen, M Åkerblom, M Kaasalainen | NFLI, Tampere Univ of Technology, Finnish Env. Institute, Finnish Geodetic Institute | Annals of Forest Science |
| *Deriving cooperative biomass resource transport supply strategies in meeting co-firing energy regulations: A case for peat and wood fibre in Ireland* | Ger Devlin, Bruce Talbot | School of Biosystems Engineering, NFLI | Applied Energy |
| *Performance of small scale straw-to-heat supply chains in Norway* | Helmer Belbo, Bruce Talbot | NFLI | WIREs Energy and Environment |
| *Systems Analysis of Ten Supply Chains for Whole Tree Chips* | Helmer Belbo, Bruce Talbot | NFLI | Forests |
| *The COST model for calculation of forest operations costs* | Pierre Ackerman, Helmer Belbo, Lars Eliasson, Anjo de Jong, Andis Lazdins, John Lyons | NFLI | International Journal of Forest Engineering |
| *Combined waste resources as compound fertiliser to spring cereals* | Brod, E., Haraldsen, T.K. & Krogstad, T | NMBU, BIOFORSK | Acta Agriculturae Scandinavica, Section B Plant and Soil Science |
| *Investigation of Additives for Preventing Ash Fouling and Sintering during Barley Straw Combustion* | Liang Wang, Øyvind Skreiberg, Michael Becidan | SINTEF ER | Applied Thermal Engineering |
| *Investigation of Biomass Ash Sintering Characteristics and the Effect of Additives* | Liang Wang, Geir Skjevrak, Johan E. Hustad, Øyvind Skreiberg | NTNU, SINTEF ER | Energy & Fuels |
| *Towards simulation of far-field aerodynamic sound from a circular cylinder using OpenFOAM* | Dmitry A. Lysenko, Ivar S. Ertesvåg, Kjell Erik Rian | NTNU, ComputIT | International Journal of Aeroacoustics |

| Title | Author(s) | Lead Partner(s) | Journal |
|---|---|---|---|
| *Investigation of additives for preventing ash fouling and sintering during barley straw combustion* | Liang Wang, Øyvind Skreiberg, Michael Becidan | SINTEF ER | Applied Thermal Engineering |
| *Numerical simulation of non-premixed turbulent combustion using the Eddy Dissipation Concept and comparing with the Steady Laminar Flamelet model* | Dmitry Lysenko, Ivar S. Ertesvåg, Kjell Erik Rian | NTNU, ComputIT | Flow, Turbulence and Combustion |
| *Methane production and energy evaluation of a farm scaled biogas plant in cold climate area* | Kristian Fjørtoft, John Morken, Jon Fredrik Hanssen, Tormod Briseid | NMBU, Bioforsk | Bioresource Technology |
| *Effects of a gradually increased load of fish waste silage in co-digestion with cow manure on methane production* | Linn Solli, Ove Bergersen, Roald Sørheim, Tormod Briseid | Bioforsk | Waste management |
| *Steam explosion pretreatment for enhancing biogas production of late harvested hay* | A. Bauer, J. Lizasoain, F. Theuretzbacher, J. W. Agger, M. Rincón, S. Menardo, M. K. Saylor, R. Enguídanos, P. J. Nielsen, A. Potthast, T. Zweckmair, A. Gronauer, S. J. Horn | NMBU, University of Natural Resources and Life Sciences (Austria) | Bioresource Technology |
| *A metagenomic study of the microbial communities in four parallel biogas reactors* | Linn Solli, Othilde Elise Håvelsrud, Svein Jarle Horn, Anne Gunn Rike | Bioforsk, Oslo University Hospital, NMBU, Norwegian Geotechnical Institute | Biotechnology for Biofuels |
| *On the Determination of Water Content in Biomass Processing* | Agger, Jane; Nilsen, Pål Jahre; Eijsink, Vincent; Horn, Svein Jarle | NMBU, Cambi AS | Bioenergy Research |
| *A C4-oxidizing lytic polysaccharide monooxygenase cleaving both cellulose and cello-oligosaccharides* | Isaksen, T; Westereng, B; Aachmann, F L; Agger, J; Kracher, D; Kittl, R; Ludwig, R.; Haltrich, D; Eijsink, V; Horn, S J | NMBU, NFLI, University of Copenhagen, University of Natural Resources and Life Sciences (Austria) | Journal of Biological Chemistry |
| *Changes in the composition of the main polysaccharide groups of oil seed rape straw following steam explosion and saccharification* | Ryden, Peter; Gautier, alizee; Wellner, Nikolaus; Tapp, Henri S.; Horn, Svein Jarle; Eijsink, Vincent; Waldron, Keith | Norwich Research Park, NMBU | Biomass and Bioenergy |
| *Influences of wet torrefaction on pelletability and pellet properties of Norwegian forest residues* | Quang-Vu Bach, Nevena Mišsljenović, Khanh-Quang Tran, Carlos Salas-Bringas, Øyvind Skreiberg | NTNU, SINTEF ER | Annual Transactions - The Nordic Rheology Society |

| Title | Author(s) | Lead Partner(s) | Journal |
|---|---|---|---|
| *A Simulation study on the torrefied biomass gasification* | Dhruv Tapasvi, Rajesh S. Kempegowda, Khanh-Quang Tran, Øyvind Skreiberg, Morten G. Grønli | NTNU, SINTEF ER | Energy Conversion and Management |
| *Torrefaction Influence on Pelletability and Pellet Quality of Norwegian Forest Residues* | Nevena Mišsljenović, Quang-Vu Bach, Khanh-Quang Tran, Carlos Salas-Bringas, and Øyvind Skreiberg | NMBU, NTNU, SINTEF ER | Energy & Fuels |
| *Torrefaction Kinetics of Norwegian Biomass Fuels* | Quang-Vu Bach, Roger A. Khalil, Khanh-Quang Tran, Øyvind Skreiberg | NTNU, SINTEF ER | Chemical Engineering Transactions |
| *Effects of $CO_2$ on wet torrefaction of biomass* | Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg, Roger A. Khalil | NTNU, SINTEF ER | Energy Procedia |
| *Wet torrefaction of forest residues* | Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg | NTNU, SINTEF ER | Energy Procedia |
| *Effects of wet torrefaction on reactivity and kinetics of wood under air combustion conditions* | Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg, Roger A. Khalil, Anh N. Phan | NTNU, SINTEF ER | Fuel |
| *Climate change implications of shifting forest management strategy in a boreal forest ecosystem of Norway* | Ryan M. Bright, Clara Antón-Fernández, Rasmus Astrup, Francesco Cherubini, Maria Kvalevåg, Anders H. Strømman | NTNU, NFLI, Cicero | Global Change Biology |
| *Land use impacts on biodiversity from kiwifruit production in New Zealand assessed with global and national datasets* | Carla R. V. Coelho, Ottar Michelsen | Landcare Research, NTNU | The International Journal of Life Cycle Assessment |
| *Linearity between temperature peak and bioenergy $CO_2$ emission rates* | Francesco Cherubini, Thomas Gasser, Ryan M. Bright, Philippe Ciais and Anders H. Strømman | NTNU, CNRS-PontsParis Tech-EHESS-AgroParis-Tech-CIRAD, CEA-CNRS- UVSQ | Nature Climate Change |
| *Biogenic $CO_2$ fluxes, changes in surface albedo and biodiversity impacts from establishment of a miscanthus plantation* | Jorgensen, S. V.; Cherubini, F.; Michelsen, O. | TU Denmark, NTNU | Journal of Environmental Management |

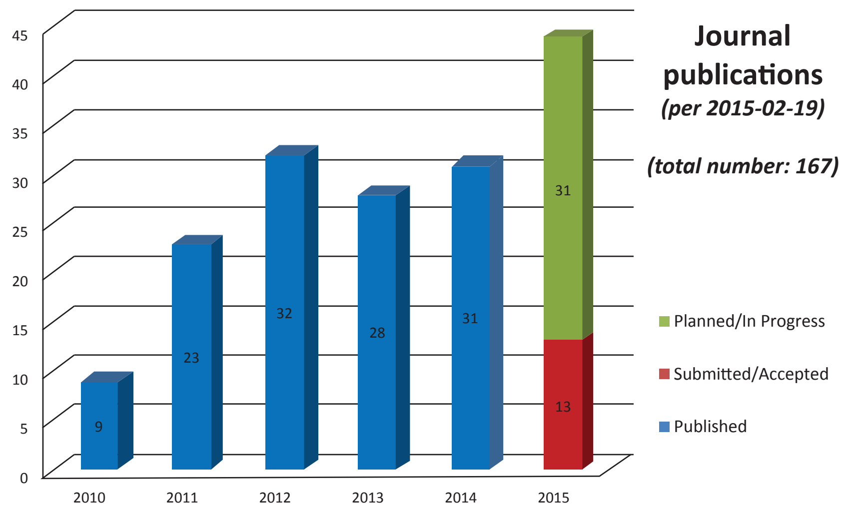


*Figure 34: Status of peer-reviewed journal papers published within CenBio.*

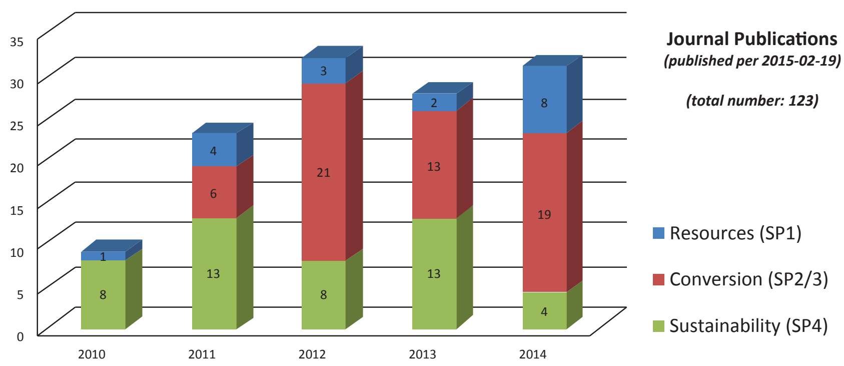


*Figure 35: Status of journal publications per sup-project.*

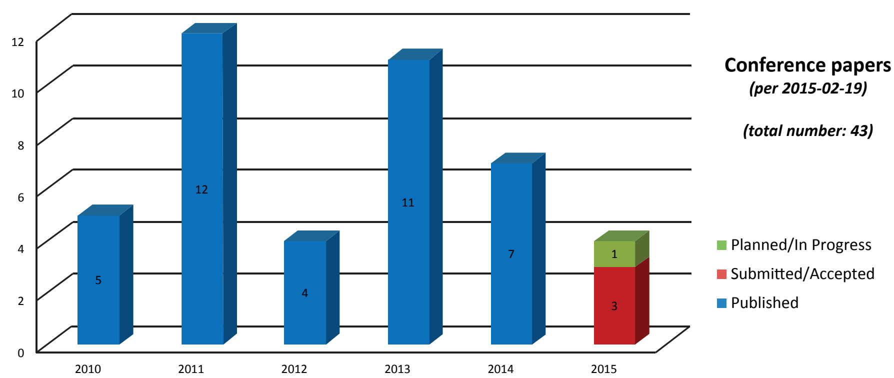


*Figure 36: Status of conference papers published within CenBio.*

## Published Conference Papers

Table 19: List of conference papers published in 2014.

| Title | Author(s) | Lead partner(s) | Conference |
|---|---|---|---|
| *Characterization of ashes from different wood parts of Norway spruce tree* | Liang Wang, Janka Dibdiakova | SINTEF-ER, NFLI | *Chemical Engineering Transactions, International Congress on Biomass, 4-7 May 2014, Florence, Italy* |
| *Syngas production from gasification of waste* | Houshfar, E.; Grimshaw, A.; Lundstrom, P. | Energos | *Proceedings Venice 2014, Fifth International Symposium on Energy from Biomass and Waste, San Servolo, Venice, Italy; 17 - 20 November 2014* |
| *Techno-economics of dry and wet-torrefaction process for improved bio-feedstocks for biorefinery applications* | Rajesh S. Kempegowda, Roger A. Khalil, Øyvind Skreiberg | NTNU, SINTEF ER | *Proceedings of 22nd European BC&E, 23-26 June 2014, Hamburg, Germany* |
| *Optimization of biocrude production through co-processing torrefied biomass with low-grade wet biomass in dual entrained flow gasification and steam hydrogasification* | Rajesh S. Kempegowda, Gonzalo del Alamo, Berta Matas Güell, Øyvind Skreiberg, Khanh-Quang Tran | NTNU, SINTEF ER | *Proceedings of 22nd European BC&E, 23-26 June 2014, Hamburg, Germany* |
| *Effects of $CO_2$ on wet torrefaction of biomass* | Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg | NTNU, SINTEF ER | *Energy Procedia (6th International Conference on Applied Energy - ICAE2014)* |
| *Wet torrefaction of forest residues* | Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg | NTNU, SINTEF ER | *Energy Procedia (6th International Conference on Applied Energy - ICAE2014)* |
| *Sintering of rye straw ash and effect of additives* | Liang Wang, Øyvind Skreiberg, Michael Becidan, Hailong Li | SINTEF-ER, Mälardalens University (Sweden) | *Energy Procedia (6th International Conference on Applied Energy - ICAE2014)* |

## Conference Presentations

Table 20: List of conference presentations given in 2014.

| Title | Author(s) | Lead partner(s) | Conference |
|---|---|---|---|
| *Wood ash as raw material for Portland cement* | Bjarte Øye | SINTEF MC | *Central European Biomass Conference, 15-18 January 2014, Graz (Austria)* |
| *System analysis of Ten Supply Chains for Whole Tree Chips* | Helmer Belbo | NFLI | *Formec-Fec Conference in Gerardmer, France, Sept 24-26 2014.* |
| *Large scale forest biomass supply for energy - Lessons learned from Finland and Sweden* | Antti Asikainen | Metla | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *How to face crisis in the forest industry?* | Olav Veum | Norges Skogeierforbund | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |

| Title | Author(s) | Lead partner(s) | Conference |
|---|---|---|---|
| *What can be done to boost the bioenergy market?* | Gunnar Olofsson | SKOG22 | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Energivirketynning - Venn eller fiende?* | Helmer Belbo | NFLI | *Grong* |
| *Choosing and using equipment and concepts for efficient biomass supply* | Helmer Belbo | NFLI | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *A Chip-Truck Trojan Chipper - a sound solution for wood-chip supply?* | Helmer Belbo | NFLI | *OSCAR 2014 conference, Knivsta, Sweden.* |
| *Techno-economics of dry and wet-torrefaction process for improved bio-feedstocks for biorefinery applications* | R. S. Kempegowda, R. A. Khalil, Ø. Skreiberg | NTNU, SINTEF ER | *Proceedings of 22nd European BC&E, 23-26 June 2014, Hamburg, Germany* |
| *Optimization of biocrude production through co-processing torrefied biomass with low-grade wet biomass in dual entrained flow gasification and steam hydrogasification* | R. S. Kempegowda, G. del Alamo, B. M. Güell, Ø. Skreiberg, K-Q. Tran | NTNU, SINTEF ER | *Proceedings of 22nd European BC&E, 23-26 June 2014, Hamburg, Germany* |
| *Effects of $CO_2$ on wet torrefaction of biomass* | Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg | NTNU, SINTEF ER | *ICAE2014 - Energy Procedia* |
| *Wet torrefaction of forest residues* | Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg | NTNU, SINTEF ER | *ICAE2014 - Energy Procedia* |
| *Ash related research activities in CenBio - Highlights and implications* | Liang Wang | SINTEF ER | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Stationary bioenergy research, use and markets in the USA - Status and reflections* | Michael J. Antal, Jr | University of Hawaii at Manoa | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Challenges and experience from the finalization of Hafslund's pellet plant* | Steffen Birkeland | Hafslund Varme AS | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Challenges in waste-to-energy industry* | Pål Mikkelsen | EGE Oslo | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *CFD study of $NO_x$ formation* | Mette Bugge | SINTEF ER | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *GWPs and GTPs for forest bioenergy and products with global coverage at 0.5 x 0.5 spatial resolution* | Cherubini, F; Huijbregts, M A.J.; Kinderman, G; Bright, R M.; Van Zelm, R; Van Der Welde, M; Strømman, A H | NTNU | *European Geoscience Union* |
| *Alternatives to GWP in LCA: temperature metrics and explicit time profiles* | Cherubini, Francesco; Levasseur, Annie | NTNU | *SETAC Conference* |

| Title | Author(s) | Lead partner(s) | Conference |
|---|---|---|---|
| *Environmental impacts of harvesting forest residues - Recents results* | Toril D. Eldhuset | NFLI | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Skogsbränsleforskning i Sverige – historisk tillbakablick och dagens trender* | Staffan Jacobson | Skogforsk (Sweden) | *Bioenergi fra skog i økologisk perspektiv 12 February 2014, Oslo* |
| *Grot i økologisk sammenheng med vekt på nye resultater fra Finland* | Heljä-Sisko Helmis-aari, L Kaarakka, M Kukkola, A-J Lindroos, A Saarsalmi, A Smo-lander, P Tamminen | Helsinki universitet Metla, NFLI | *Bioenergi fra skog i økologisk perspektiv 12 February 2014, Oslo* |
| *Calibrating the soil carbon dynamics of Romul using Norwegian forest sites* | Silje Skår | NMBU/NFLI | *CAR-ES meeting 19-21 March 2014, Birstonas, Lithuania* |
| *Bioenergi fra skog i økologisk perspektiv: Framtida for grot som biobrensel* | Johannes Bergum | Mjøsen skog (mem-ber of SKOGEIER) | *Bioenergi fra skog i økologisk perspektiv 12 February 2014, Oslo* |
| *Effects of wood ash in forest* | Kjersti Holt Hanssen, Nicholas Clarke, Simen Gjølsjø, Janka Dibdiakova | NFLI | *CenBio ash miniseminar/work-shop 27 May 2014, Værnes* |
| *Communicating on bioenergy R&D: how to deal with media, controversy and public perception?* | Tomas Moe Skjølsvold | NTNU | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Finding opportunities for innovation in your research* | Nils Spidsøe | SINVENT AS | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Status SP6 - Value chain assessment* | Anders H. Strømman | NTNU | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Progress and status of the Centre* | Berta Matas Güell, Odd Jarle Skjel-haugen | SINTEF ER, NMBU | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Current trends of the EU Commission regarding bioenergy research* | Jonas Helseth | Bellona Europa | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Scientific Advisors' comments and advice on CenBio vs. current bio-energy trends* | Heikki Pajuja, Mikko Hupa, Michael J. Antal Jr. | Metsäteho Oy, Åbo Akademi, Univ of Hawaii at Manoa | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Foresight process:*<br>*Status and road ahead* | Berta Matas Güell | SINTEF ER | *CenBio Days 2014, 26-28 March 2014, Lillestrøm* |
| *Recent insights into the enzymatic conversion of lignocellulosic biomass* | Eijsink, Vincent | NMBU | *Annual Plant Biotech Denmark Meeting* |
| *Novel structures and functions of lytic polysaccharide monooxygenases* | Horn, S J; Agger, J; Isaksen, T; Forsberg, Z; Ludwig, R.; Macken-zie, A; Vaaje-Kolstad, G; Varnai, A; Wes-tereng, B; Eijsink, V | NMBU, University of natural resourc-es and life sciences (Vienna) | *36th symposium on biotechnology for fuels and chemicals* |

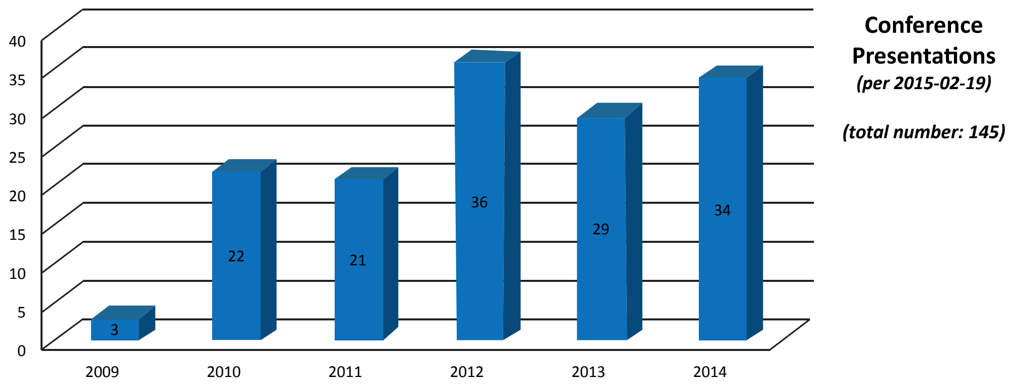


*Figure 37: Status of conference presentations performed within CenBio.*

## Chapters in books

Table 21: List of books with contributions from CenBio published in 2014.

| Title | Author(s) | Lead partner | Pages | ISBN |
|---|---|---|---|---|
| *Development and use of forest decision support systems in Norway* | Bergseng, E., Eid, T. & Gobakken, T. | NMBU | 16 | 978-91-576-9236-8 |
| *Renewable Heating and Cooling platform - Biomass technology roadmap* | Lara Mertens, Niall Goodwin, Øyvind Skreiberg et al. (as contributors) | SINTEF ER | 44 | |
| *Heating of buildings with low heating demand: Stable heat release and distribution from batch combustion of wood (StableWood)* | Mette Bugge, Øyvind Skreiberg, Morten Seljeskog | SINTEF ER | 20 | 978-82-594-3660-3 |

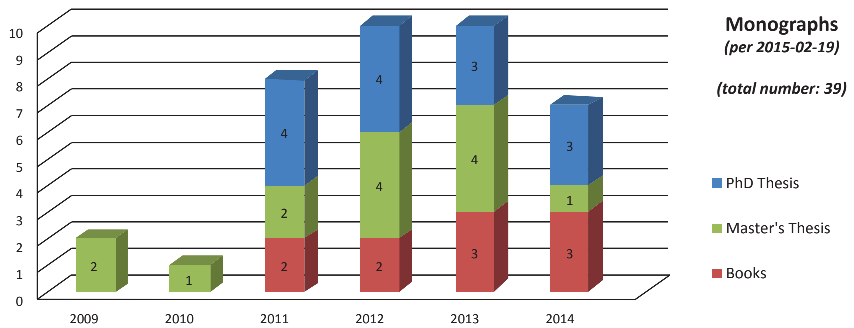


*Figure 38: Status of monographs published within CenBio.*

## Reports

Table 22: List of reports finalized in 2014.

| Title | Author(s) | Lead partner | Class. |
|---|---|---|---|
| *Annual Work Plan 2015* | Einar Jordanger (+CMT) | SINTEF-ER | *Restricted* |
| *Progress report 1 2014* | Alexis Sevault | SINTEF-ER | *Restricted* |
| *Progress report 2 2014* | Alexis Sevault | SINTEF-ER | *Restricted* |
| *Accounts Report 2013* | Einar Jordanger | SINTEF-ER | *Restricted* |
| *Annual Report 2013* | Alexis Sevault | SINTEF-ER | *Public* |
| *Foresight Report Bioenergy* | B. Matas Guell, E. Jordanger, P. K. Rørstad, A. Brunsvold, J. P. Jakobsen, L. Rydså, A. Sevault, M. Becidan, O. J. Skjelhaugen | SINTEF-ER NMBU | *Restricted* |
| *Grot fra Taubane* | Erik Nordhagen, Leif Kjøstelsen, Simen Gjløsjø, Helmer Belbo | NFLI | *Public* |
| *Solid biofuels from forest – fuel specification and quality assurance* | Janka Dibdiakova, Simen Gjølsjø, Liang Wang | NFLI | *Restricted* |
| *Characterisation of MSWI ashes I* | Bjarte Øye | SINTEF-MC | *Restricted* |
| *Measurement campaign at ES Nord – Planning* | Mette Bugge, Roger Khalil | SINTEF-ER | *Restricted* |
| *Measurement campaign (Akershus Energi)* | Roger Khalil, Per Carlsson | SINTEF-ER | *Restricted* |
| *Report on suggestions for management guidelines for sustainable forest harvesting for bioenergy (I4.2.1)* | Nicholas Clarke | NFLI | *Public* |
| *Collection of Journal Paper Abstracts* | Stine Lund Davanger, Alexis Sevault, Einar Jordanger | SINTEF-ER | *Restricted* |

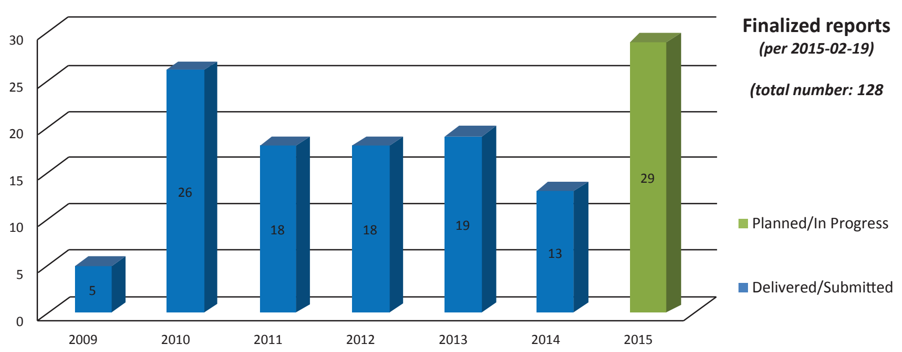


*Figure 39: Status of technical reports published within CenBio.*

### Media contributions

We have listed most of the contributions from CenBio personnel during 2014, mostly in Norwegian media, in Table 23.

Table 23: List of media contributions 2014.

| Title | Author(s) | Lead partner(s) | Media |
|---|---|---|---|
| *CenBio forskere på NRK1 i Forbrukerinspektørene* | Morten Seljeskog, Simen Gjølsjø | SINTEF ER, NFLI | *NRK1* |
| *Dette må du for all del ikke fyre i peisen med* | Camilla Veka, Morten Seljeskog | SINTEF ER | *NRK.no* |
| *Den dummeste loven som noen gang er skrevet* | Kjersti Blehr Lånkan, Morten Seljeskog | SINTEF ER | *Bergens Tidende* |
| *Gamle ovner til ny glede* | Kjersti Blehr Lånkan, Morten Seljeskog | SINTEF ER | *Klikk.no and ABCNyheter* |
| *Bioenergy future* | Øyvind Skreiberg, Morten Seljeskog, Laurent Georges | SINTEF ER, NTNU | *Pan European Networks Government* |
| *Biomasse i form av pellets er et godt alternativ når oljefyr skal fases ut!* | Morten Seljeskog, Øyvind Skreiberg | SINTEF ER | *Nobio.no* |
| *Pellets et godt alternativ* | Morten Seljeskog | SINTEF ER | *Tekniskenyheter.no* |
| *NÅR OLJEFYRER SKAL KASTES UT: - Bioenergi er den beste løsningen!* | Per Henriksen, Morten Seljeskog, Øyvind Skreiberg | SINTEF ER | *VVS Forum* |
| *Pristisjetung pris til Allma-samarbeidet* | Geir Korsvold | | *allma.no* |
| *Innovasjonspris til Mjøsen Skog* | Berit Sanness | | *mjosen.no* |
| *Innovasjonspris til Mjøsen Skog* | Åsmund Lang | | *Skog.no* |
| *Tildeles innovasjonspris for smarte bioenergiløsninger* | Lars Sandved Dalen | NFLI | *vvsforum.no* |
| *Mjøsen Skog fikk innovasjonspris* | Lars Dal | UMB, NFLI | *umb.no* |
| *Mjøsen Skog fikk innovasjonspris for smarte bioenergiløsninger* | Lars Sandved Dalen | NFLI | *skogoglandskap.no* |
| *Klimaløsningen* | Lie, Øystein; Hertwich, Edgar G.; Strømman, Anders Hammer; Müller, Daniel Beat; Cherubini, Francesco; Gibon, Thomas | NTNU | *Dagens Næringsliv* |
| *A global challenge* | Nancy Reney Bazilchuk, Edgar G. Hertwich, Thomas Gibon, Francesco Cherubini | NTNU | *gemini.no* |
| *Kvist og kvas blir edelt kull* | Lars Martin Hjorthol, Øyvind Skreiberg | SINTEF ER | *Gemini (reproduced on forskning.no, Aftenposten nett, Adresseavisen nett, etc ... )* |
| *Lopwood and brushwood make high-grade charcoal* | Lars Martin Hjorthol, Øyvind Skreiberg | SINTEF ER | *Gemini* |

| Title | Author(s) | Lead partner(s) | Media |
|---|---|---|---|
| *Utfordringer i kø - Løsninger på vei* | Morten Seljeskog, Øyvind Skreiberg | SINTEF ER | *Dovremagasinet* |
| *Nei, ikke fyr med denne på peisen* | Maria Elsness | SINTEF ER | *NRK.no* |
| *Peiskos på sparebluss* | Lars Martin Hjorthol, Øyvind Skreiberg | SINTEF ER | *Gemini (also in Adresse Avisen)* |
| *Test av tennbriketter* | Alexander Berg, Morten Seljeskog | SINTEF ER | *Klikk.no* |
| *Framtidens vedovner* | Jøte Toftaker, Øyvind Skrei-berg, Laurent Georges | SINTEF ER, NTNU | *NRK P1 Trøndelag* |
| *Innslag med forsker på fransk/ tysk TV* | | SINTEF ER/EGE | *TV* |

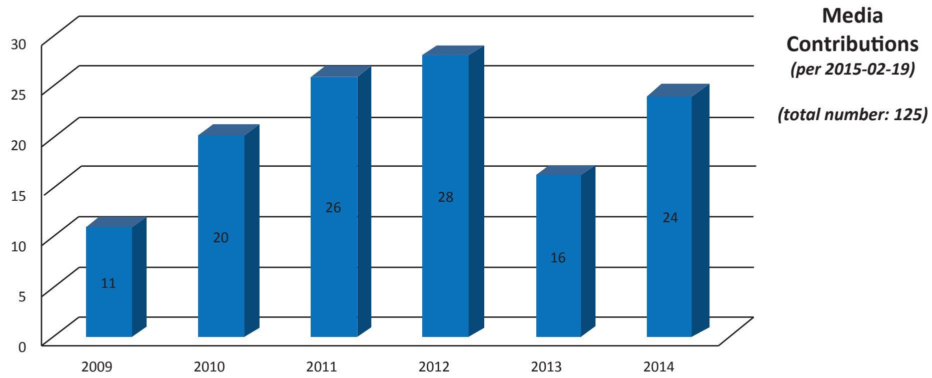


*Figure 40: Status of media contributions published within CenBio.*

## D. Deliverables List

AWP2014 included a total of **68** deliverables. Of these, **65** were planned to be finalized in 2014. 17 deliverables were delayed from 2013 and transferred in February 2014 to the operative Deliverables list for 2014. Hence a total of **82** deliverables were scheduled to be finalised in 2014.

During 2014, **32** new deliverables were added to the 2014 Deliverables list. Some partners have produced more publications and reports than planned. In some cases, new publications with co-funding from CenBio have been added to the list, and in other cases, a planned deliverable has been split into two deliverables, as for example, a presentation at a conference and the associated proceedings paper is counted as two deliverables.

The total number of deliverables in Table 24 is therefore **117**, with **114** deliverables due in 2014.

During the year, **8** deliverables were cancelled and **26** deliverables have not been finalized for various reasons. The delayed deliverables have been transferred to the 2015 Deliverables list. Almost all delays and cancellations can be explained by the following causes:

- Delayed recruitments
- Work overload from researchers or use partners
- Breakdown of instruments
- Delayed deliveries
- Two/three deliverables merged

In total, **80** deliverables were finalized in 2014 (**123** % completion compared to AWP14).

In Table 24, the deliverables present in the operative Deliverables list for 2014 are shown. Most of the finalized deliverables can be accessed via the provided link (to the CenBio eRoom – restricted to CenBio partners). The type of deliverables is indicated:

- CP stands for "Conference Paper"
- JP for "Journal Publication"
- MR for "Management Report"
- O for "Other"
- PR for "Presentation"
- PT for "Pop-Tech article"
- TR for "Technical Report"

Table 24: List of Deliverables 2014. The first column contains the links to the finalized deliverables in the Cenbio eRoom (access restricted to CenBio members).
*: In column "New", "n" stands for new deliverables, while "x" stands for the deliverables from 2013.

| Del. No. | Deliverable title | Lead partner | Dated | Type | New* |
|---|---|---|---|---|---|
| D0.1.1_7 | *Annual Work Plan 2015* | SINTEF-ER | 31.12.2014 | MR | |
| D0.1.2_61 | *Progress Report 1 2014* | SINTEF-ER | 30.05.2014 | MR | |
| D0.1.2_62 | *Progress Report 2 2014* | SINTEF-ER | 01.12.2014 | MR | |
| D0.1.3_5 | *Accounts Report 2013* | SINTEF-ER | 24.01.2014 | MR | |
| D0.1.4_5 | *Annual Report 2013* | SINTEF-ER | 14.03.2014 | MR | |
| D0.1.5 | *Foresight Bioenergy Report* | SINTEF-ER | 30.09.2014 | MR | |
| D1.1.12 | *Biomass expansion factors for spruce, pine and broad leaved trees in Norway* | NFLI | Delayed | JP | |
| D1.1.16 | *Biomass equations for birch* | NFLI | Delayed | PT | |
| D1.1.18 | *Adjacency constraints in forestry - a simulated annealing approach comparing different candidate solution generators* | NMBU | 30.03.2014 | JP | |
| D1.1.19 | *Tree root system characterization and volume estimation by terrestrial laser scanning and quantitative structure modelling* | NFLI | 21.05.2014 | JP | |
| D1.1.20 | *Biomass equations for below-ground biomass of birch* | NFLI | Delayed | JP | |
| D1.1.21 | *Impact of maximum opening area constraints on profitability biomass availability – case of Oslo municipality forest* | NMBU | 01.12.2014 | JP | |
| D1.1.22 | *PhD-thesis and defence Paulo Borges* | NMBU | 01.09.2014 | O | |

| | | | | | |
|---|---|---|---|---|---|
| D1.1.23 | *Development and use of forest decision support systems in Norway* | NMBU | 25.08.2014 | CB | n |
| D1.1.25 | *Modeling green-up constraints in forest harvest scheduling subject to maximum area restrictions* | NMBU | 23.10.2014 | JP | n |
| D1.2.4 | *Good practice guidelines for biomass production studies* | NFLI | Cancelled | TR/JP | x |
| D1.2.5_3 | *Network involved in supplying woody biomass for energy* | NFLI | Cancelled | JP | x |
| D1.2.6 | *Road Transport / Transport economic gains in new combi-truck concepts in an applied setting in Norway* | NFLI | Cancelled | TR | x |
| D1.2.13 | *Simple decision support tool for strategic evaluation of supply chain alternatives* | NFLI | Cancelled | TR | x |
| D1.2.14 | *Joint supply chain evaluation* | NFLI | Delayed | TR/JP | |
| D1.2.15 | *Input to SP6 Value Chains* | NFLI | Planned 2015 | O | |
| D1.2.17 | *Grot fra taubane (Recovery of logging residues from cable yarding)* | NFLI | 01.03.2014 | TR | |
| D1.2.19 | *Systems Analysis of Ten Supply Chains for Whole Tree Chips* | NFLI | 25.08.2014 | JP | |
| D1.2.20 | *Assessment how various supply chain configurations affect design criteria, options for location and costs of temporary roadside biomass terminals* | NFLI | Planned 2015 | JP | |
| D1.2.21 | *The COST model for calculation of forest operations costs* | NFLI | 01.03.2014 | JP | x |
| D1.2.22 | *Energivirketynning - Venn eller fiende?* | NFLI | 23.05.2014 | PR | n |
| D1.2.23 | *Choosing and using equipment and concepts for efficient biomass supply* | NFLI | 26.03.2014 | PR | n |
| D1.2.24 | *A Chip-Truck Trojan Chipper - a sound solution for wood-chip supply?* | NFLI | 25.06.2014 | PR | n |
| D1.3.10 | *Slagging properties of Northland forest trees* | NFLI/SINTEF-ER | Cancelled | JP | x |
| D1.3.11 | *Measuring of moisture content in wood chips with near infrared spectroscopy* | NFLI | Planned 2015 | JP | |
| D1.3.12 | *Characterization of Ashes from Different Wood Species from Norway Spruce* | SINTEF-ER | 17.02.2014 | CP | |
| D1.3.13 | *Value chain analyses; participation for the development of the work methodology* | NFLI/SINTEF-ER | Delayed | O | |
| D1.3.15 | *Solid biofuels from forest - fuel specification and quality assurance* | NFLI/ SINTEF-ER | 21.05.2014 | TR | x |
| D1.3.17 | *Behavior of inorganic elements during pyrolysis and combustion of biomass fuels* | SINTEF-ER | Delayed | JP/CP | |
| D1.3.18 | *Measuring of moisture content in wood chips with near infrared spectroscopy* | NFLI | Cancelled | JP | |
| D1.3.19 | *Inherent properties in forest residues of Scots pine* | NFLI | Delayed | TR/JP | |
| D1.4.5 | *Efficiency of bottom wood ash as K fertiliser to spring cereals and ryegrass* | BIOFORSK, NMBU | Delayed | JP | |

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|---|---|---|---|---|---|
| **D1.4.10** | *Evaluation of chemical extractions methods for determination of plant available phosphorus in ashes and other P rich waste materials* | **BIOFORSK/ NMBU** | Delayed | JP | |
| **D1.4.11** | *Using wood ashes as fertiliser in agriculture and urban greening* | **BIOFORSK** | 27.05.2014 | PR | |
| **D1.4.14** | *Properties of MSWI ash from Norwegian bioenergy plants – potential for treatment and utilization* | **SINTEF MC** | 10.08.2014 | TR | |
| **D1.4.15** | *Quality of ash from different combustion technologies* | **BIOFORSK** | Delayed | TR | |
| **D2.1.10_6** | *IEA Task 32 activity report 2014* | **SINTEF-ER** | Continuous | O | |
| **D2.1.22** | *Modelling to optimise heat/CHP plants* | **NTNU** | Delayed | JP | |
| **D2.1.23** | *CenBio ash seminar: opportunities and challenges* | **SINTEF-ER** | 24.06.2014 | O | |
| **D2.1.24** | *PhD Thesis Dmitry Lysenko: On Numerical Simulation of Turbulent Flows and Combustion* | **NTNU** | 26.02.2014 | O | n |
| **D2.1.25** | *Towards simulation of far-field aerodynamic sound from a circular cylinder using OpenFOAM* | **NTNU** | 14.02.2014 | JP | n |
| **D2.1.26** | *Sintering of rye straw ash and effect of additives* | **SINTEF-ER** | 05.03.2014 | CP | n |
| **D2.1.27** | *Investigation of additives for preventing ash fouling and sintering during barley straw combustion* | **SINTEF-ER** | 26.05.2014 | JP | n |
| **D2.1.28** | *Numerical simulation of non-premixed turbulent combustion using the Eddy Dissipation Concept and comparing with the Steady Laminar Flamelet model* | **NTNU** | 03.06.2014 | JP | n |
| **D2.2.11_6** | *IEA Task 33 activity report 2014* | **SINTEF-ER** | Continuous | O | |
| **D2.2.16** | *Ash & trace metals chemistry: thermodynamic equilibrium database (working title: S-Cl-Na-K chemistry during MSW gasification: a thermodynamic study )* | **SINTEF-ER, Energos** | 03.12.2014 | CP | |
| **D2.2.17** | *Syngas production from gasification of waste* | **ENERGOS** | 17.11.2014 | CP | n |
| **D2.3.14** | *High temperature charcoal carbonization (working title)* | **SINTEF-ER** | Cancelled | JP/ CP | x |
| **D2.4.6_6** | *Minutes from IEA Task 37 meetings 2013* | **BIOFORSK** | Continuous | O | |
| **D2.4.11** | *Effect of pretreatment on anaerobic digestion* | **BIOFORSK** | Delayed | TR | x |
| **D2.4.12** | *Methane production and energy evaluation of a farm scaled biogas plant in cold climate area* | **NMBU, BIOFORSK** | 22.06.2014 | JP | x |
| **D2.4.13** | *Effects of a gradually increased load of fish waste silage in co-digestion with cow manure on methane production* | **BIOFORSK, NMBU** | 10.04.2014 | JP | x |
| **D2.4.15** | *Steam explosion pretreatment for enhancing biogas production of late harvested hay* | **NMBU** | 11.05.2014 | JP | x |
| **D2.4.19** | *A metagenomic study of the microbial communities in four parallel biogas reactors* | **BIOFORSK** | 04.09.2014 | JP | x |
| **D2.4.20** | *AD microbial community structure response to changed feed* | **BIOFORSK** | Delayed | JP | |
| **D2.4.21** | *Lignocellolytic substrate* | **NMBU** | Delayed | JP | |
| **D2.4.22** | *On the determination of water content in biomass processing* | **NMBU** | 01.03.2014 | JP | n |
| **D2.4.23** | *A C4-oxidizing lytic polysaccharide monooxygenase cleaving both cellulose and cello-oligosaccharides* | **NMBU** | 31.01.2014 | JP | n |

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|---|---|---|---|---|---|
| D2.4.24 | *Changes in the composition of the main polysaccharide groups of oil seed rape straw following steam explosion and saccharification* | **NMBU/NFLI** | 01.02.2014 | JP | n |
| D2.5.5 | *Torrefaction Influence on Pelletability and Pellet Quality of Norwegian Forest Residues* | **NMBU** | 26.05.2014 | JP | n |
| D2.5.6 | *Torrefaction Kinetics of Norwegian Biomass Fuels* | **NTNU** | 26.05.2014 | JP | n |
| D2.5.7 | *Effects of $CO_2$ on wet torrefaction of biomass* | **NTNU** | 30.09.2014 | JP | n |
| D2.5.8 | *Wet torrefaction of forest residues* | **NTNU** | 30.09.2014 | JP | n |
| D2.5.9 | *Effects of wet torrefaction on reactivity and kinetics of wood in air combustion* | **NTNU** | 05.08.2014 | JP | n |
| D2.5.10 | *Influences of wet torrefaction on pelletability and pellet properties of Norwegian forest residues* | **NTNU** | 30.09.2014 | JP | n |
| D2.5.11 | *Effects of wet torrefaction on pyrolysis of woody biomass fuels* | **NTNU** | 30.10.2014 | JP | n |
| D2.5.12 | *A Simulation study on the torrefied biomass gasification* | **NTNU** | 16.11.2014 | JP | n |
| D2.5.13 | *Torrefaction of wet and dry forest residues in subcritical water* | **NTNU** | 30.10.2014 | JP | n |
| D2.5.14 | *$CO_2$ Gasification of torrefied wood. A kinetic study* | **SINTEF-ER** | 13.10.2014 | JP | n |
| D3.1.4_6 | *Reports from standardization meetings* | **SINTEF-ER** | 30.12.2014 | O | |
| D3.1.5 | *On the proper integration of wood stoves in passive houses under cold climates* | **NTNU, SINTEF-ER** | 01.04.2014 | JP | n |
| D3.2.6_6 | *IEA Task 36 participation* | **SINTEF-ER** | Continuous | O | |
| D3.2.13 | *Bottom ash from WtE: national survey* | **SINTEF-ER** | Delayed | O | |
| D3.2.14 | *Norwegian Waste-to-Energy (WtE) in 2030: challenges and opportunities* | **SINTEF-ER** | 05.12.2014 | CP | |
| D3.3.7 | *Long term ChlorOut test* | **VRD** | Delayed | TR | |
| D3.3.8 | *Operational experiences from a ChlorOut installation in a BFB boiler* | **VRD** | Delayed | TR | |
| D3.3.9 | *The effect of oxygen and volatile combustibles on $NO_x$, CO and KCl during injection of ammonium sulphate* | **VRD** | 28.01.2015 | JP | |
| D3.4.6 | *Measurement campaign planning (Akershus Energi)* | **SINTEF-ER** | 26.05.2014 | TR | x |
| D3.4.8 | *Measurement campaign (Akershus Energi)* | **SINTEF-ER** | 05.06.2014 | TR | |
| D3.4.9 | *$NO_x$ formation – CFD study* | **SINTEF-ER** | 30.10.2014 | JP | x |
| D4.1.41 | *Assessment of the biogeochemical and biogeophysical climate impact of bioenergy* | **NTNU** | Delayed | JP | |
| D4.1.42 | *Linearity between temperature peak and bioenergy $CO_2$ emission rates* | **NTNU** | 05.09.2014 | JP | n |
| D4.1.43 | *Biogenic $CO_2$ fluxes, changes in surface albedo and biodiversity impacts from establishment of a miscanthus plantation* | **NTNU** | 06.09.2014 | JP | n |
| D4.2.13 | *Influence of different tree-harvesting intensities on forest soil carbon stocks in 2 boreal and northern temperate forest ecosystems* | **NFLI** | 15.12.2014 | JP | |

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|---|---|---|---|---|---|
| D4.2.17 | *Report on suggestions for management guidelines for sustainable forest harvesting for bioenergy (I4.2.1)* | **NFLI** | 06.05.2014 | TR | |
| **D4.2.18** | *Journal paper on ecological consequences of increased biomass removal from forests using whole-tree harvesting for bioenergy* | **NFLI** | Delayed | JP | |
| **D4.2.19** | *Report on suggestions for criteria and indicators for sustainable forest harvesting for bioenergy (I4.2.4)* | **NFLI** | Delayed | TR | |
| D.4.2.20 | *Skogsbränsleforskning i Sverige – historisk tillbakablick och dagens trender* | **Skogforsk, NFLI** | 12.02.2014 | PR | n |
| D4.2.21 | *Grot i økologisk sammenheng med vekt på nye resultater fra Finland* | **Metla, NFLI** | 12.02.2014 | PR | n |
| D4.2.22 | *Calibrating the soil carbon dynamics of Romul using Norwegian forest sites* | **NMBU, NFLI** | 20.03.2014 | PR | n |
| D4.2.23 | *Bioenergi fra skog i økologisk perspektiv: Framtida for grot som biobrensel* | **Mjøsen Skog, NFLI** | 12.02.2014 | PR | n |
| D4.2.24 | *Effects of wood ash in forest* | **NFLI** | 27.05.2014 | PR | n |
| **D4.3.8** | *Costs and production inputs of bioenergy production* | **NMBU** | Cancelled | TR | x |
| **D4.3.11** | *Conceptual report on what is meant by sustainable bioenergy production, and discussion of corresponding criteria and indicators* | **NMBU** | Delayed | TR | |
| **D4.3.16** | *Estimation of the carbon leakage effects of increased harvest in Norway* | **NMBU** | Delayed | JP | |
| **D4.3.22_1** | *Impacts of forest bioenergy and policies on the forest sector in Europe – what do we know?* | **NMBU** | Delayed | TR | |
| **D4.3.22_2** | *Impacts of forest bioenergy and policies on the forest sector in Europe – what do we know? Policy brief* | **NMBU** | Delayed | O | |
| **D4.3.25** | *Impacts of subsidies on the future energy prices and competition over fiber* | **NMBU** | Delayed | PT | |
| D5.1.11 | *Development and delivery of Post graduate course in Life cycle assessment of bioenergy systems* | **NTNU** | 31.12.2014 | O | |
| **D5.2.18_6** | *4 industry workshops* | **SINTEF-ER** | Continuous | O | |
| **D5.2.19** | *3 industry cases* | **NMBU** | Continuous | O | x |
| D5.2.20_6 | *Scientific publishing: 20 scientific papers submitted, 10 conferences papers* | **NMBU** | Continuous | O | |
| D5.2.21_6 | *CenBio website* | **SINTEF-ER, NMBU** | Continuous | O | |
| D5.2.22_6 | *CenBio Days March 2014* | **SINTEF-ER, NMBU** | 28.03.2014 | O | |
| D5.2.23_6 | *External conferences and presentations: 10 international conferences, seminars, workshops; 10 presentations* | **NMBU, SINTEF-ER** | Continuous | O | |
| D5.2.24_6 | *Popular publishing: 20 popular articles and press news* | **NMBU + all WPs** | Continuous | O | |
| D5.2.26_6 | *CenBio Strategic Day October 2014* | **SINTEF-ER + NMBU** | 29.10.2014 | O | |

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|---|---|---|---|---|
| **D5.2.27** | *CenBio International Conference 2015 Programme and invitations* | **NMBU, SINTEF-ER** | Delayed | O |
| **D5.2.28** | *Collection of journal paper abstracts (published within CenBio)* | **SINTEF-ER** | 06.01.2014 | MR |
| **D5.3.8-4** | *Status of CenBio Innovations, 4th version* | **SINTEF-ER** | 15.01.2015 | O |
| **D5.3.10-4** | *Extending the CenBio activities - Status* | **SINTEF-ER** | 20.01.2015 | O |
| **D5.3.11-4** | *Award the 4th Bioenergy Innovation Award* | **SINTEF-ER** | 05.05.2014 | O |

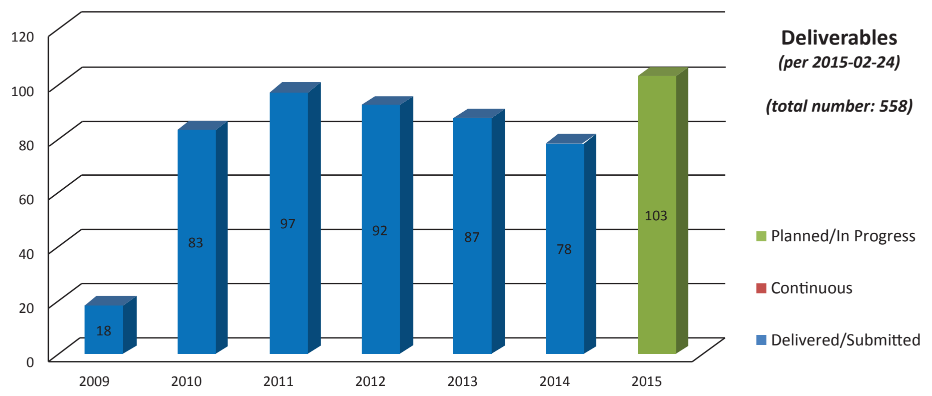


*Figure 41: Status of deliverables achieved within CenBio.*

## E. List of events organized by CenBio*

*: Table 25 does not include the more regular meetings organized through CenBio, such as:

- EERA, COST, SKOG22, BIONET, PREWIN and IEA Meetings
- Centre Management Team (CMT) Meetings (ca. 10 per year)
- Executive Board (EB) Meetings (ca. 5 per year)
- General Assembly (once a year during CenBio Days)
- Regular meetings with partners
- RCN Meetings (kontaktmøter, etc...)

Table 25: List of events organised by CenBio from 2009 to 2014

| CenBio events | SP | Year |
|---|---|---|
| CenBio Kick Off, Ås, 15 May 2009 | SP0 | 2009 |
| CenBio Meeting – Annual Work Plan 2010, Ås, 26 November 2009 | SP0 | 2009 |
| CenBio Days 2010, Hafslund Sarpsborg, 13-14 January 2010 | SP0 | 2010 |
| 1st CenBio Graduate School Workshop, Hafslund Sarpsborg, 13 January 2010 | SP5 | 2010 |
| 1st Innovation Workshop, Trondheim, 17 November 2010 | SP5 | 2010 |
| CenBio Days 2011, Trondheim, 17-18 January 2011 | SP0 | 2011 |
| 2nd CenBio Graduate School, Trondheim, 17 January 2011 | SP5 | 2011 |
| 1st Bioenergy Innovation Award, Trondheim, 18 January 2011 | SP5 | 2011 |

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|---|---|---|
| Site visit, Ås, 8 June 2011 | SP0 | 2011 |
| 2nd Innovation Workshop, Trondheim, 1 September 2011 | SP5 | 2011 |
| LCA + Annual Work Plan 2012, Trondheim, 1-2 September 2011 | SP0 | 2011 |
| Workshop on pretreatment, Ås, 2011 | SP1 | 2011 |
| CenBio Days 2012, Ås, 18-19 January 2012 | SP0 | 2012 |
| 3rd CenBio Graduate School Workshop, Ås, 18 January 2012 | SP5 | 2012 |
| 2nd Bioenergy Innovation Award, Trondheim, 18 January 2012 | SP5 | 2012 |
| Site visit, Trondheim, 23 May 2012 | SP0 | 2012 |
| Study Tour in Austria before Midterm evaluation, Austria, 21-25 May 2012 | SP0 | 2012 |
| **CenBio events** | **SP** | **Year** |
| CenBio Meeting: Midterm Evaluation, SWOT and Roadmap, Værnes, 22 May 2012 | SP0 | 2012 |
| Cambi Biogas Summer Seminar, Ås, 18-20 June 2012 | SP5 | 2012 |
| Midterm Evaluation - Site Visit, Ås, 20 March 2013 | SP0 | 2013 |
| CenBio Days 2013, PFI, Trondheim, 10-11 April 2013 | SP0 | 2013 |
| 3rd Bioenergy Innovation Award, PFI, Trondheim, 10 April 2013 | SP5 | 2013 |
| 3rd Innovation Workshop, SINTEF, Trondheim, 10 April 2013 | SP5 | 2013 |
| SP6 Meeting, Scandic Solsiden,Trondheim, 30 October 2013 | SP6 | 2013 |
| CenBio Strategic Day 2013, NOVA, Trondheim, 31 October 2013 | SP0 | 2013 |
| STOP Project Workshop, SINTEF, Trondheim, 5 December 2013 | SP2 | 2013 |
| SP6 Workshop, Radisson Blu, Værnes, February 2014 | SP6 | 2014 |
| CenBio Days 2014, Thon Hotel Arena, Lillestrøm, 26-28 March 2014 | SP0 | 2014 |
| 4th Bioenergy Innovation Award, Thon Hotel Arena, Lillestrøm, 27 March 2014 | SP5 | 2014 |
| CenBio Ash Seminar, Værnes, 27 May 2014 | SP2 | 2014 |
| Site visit, Værnes, 5 June 2014 | SP0 | 2014 |
| CenBio Strategic Days 2014, Ås Campus / Gardemoen, 29-30 October 2014 | SP0 | 2014 |

## F. List of Partners – short names

For more convenience, unique short names for all partners have been defined within the present document. Corresponding entity legal name can found in Table 26.

Table 26: Short names of partners.

| No | Short name | Entity legal name |
|---|---|---|
| 01 | **NMBU** | Norwegian University of Life Sciences(**Host institution**) |
| 02 | **SINTER-ER** | SINTEF Energy Research (**Coordinating institution**) |
| 03 | **NTNU** | Norwegian University of Science and Technology |
| 04 | **BIOFORSK** | Bioforsk |
| 05 | **NFLI** | Norwegian Forest and Landscape Institute |
| 06 | **SINTEF-MC** | SINTEF Foundation (Materials and Chemistry) |
| 07 | **VRD** | Vattenfall Research and Development AB (Sweden) |
| 08 | **AKERSHUS** | Akershus Energi AS |
| 09 | **SKOGEIER** | Norges Skogeierforbund |

| | | |
|---|---|---|
| 12 | **HAFSLUND** | Hafslund ASA |
| 13 | **STATKRAFT** | Statkraft Varme AS |
| 19 | **EGE** | Oslo Kommune Energigjenvinningsetaten |
| 21 | **VHN** | Vattenfall Distribution and Sales, business unit Heat |
| 22 | **ENERGOS** | Energos AS |
| 23 | **CAMBI** | Cambi AS |
| 24 | **JØTUL** | Jøtul AS |
| 26 | **GKAS** | Norsk Kleber AS |

## G. References


*R&D Agreement between RCN and the host institution NMBU*
*Consortium Agreement*

*Annual Work Plan 2014*
*Annual Report 2011*
*Annual Report 2012*
*Annual Report 2013*

*CenBio website: www.cenbio.no*
*RCN's FME-website: www.forskningsradet.no/prognett-energisenter/Forside/*

## Footnotes:

1 Smith, A., Granhus, A., Astrup, R., Bollandsås, O.M., Petersson, H. 2014. *Functions for estimating aboveground biomass of birch in Norway.* Scandinavian Journal of Forest Research. 29(6) 565-578.

2 Smith, A., Astrup, R., Raumonen, P., Liski, J., Krooks, A., Kaasalainen, S., Åkerblom, M., Kaasalainen, M. 2014. *Tree Root System Characterization and Volume Estimation by Terrestrial Laser Scanning and Quantitative Structure Modeling.* Forests. 5: 3274-3294.

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