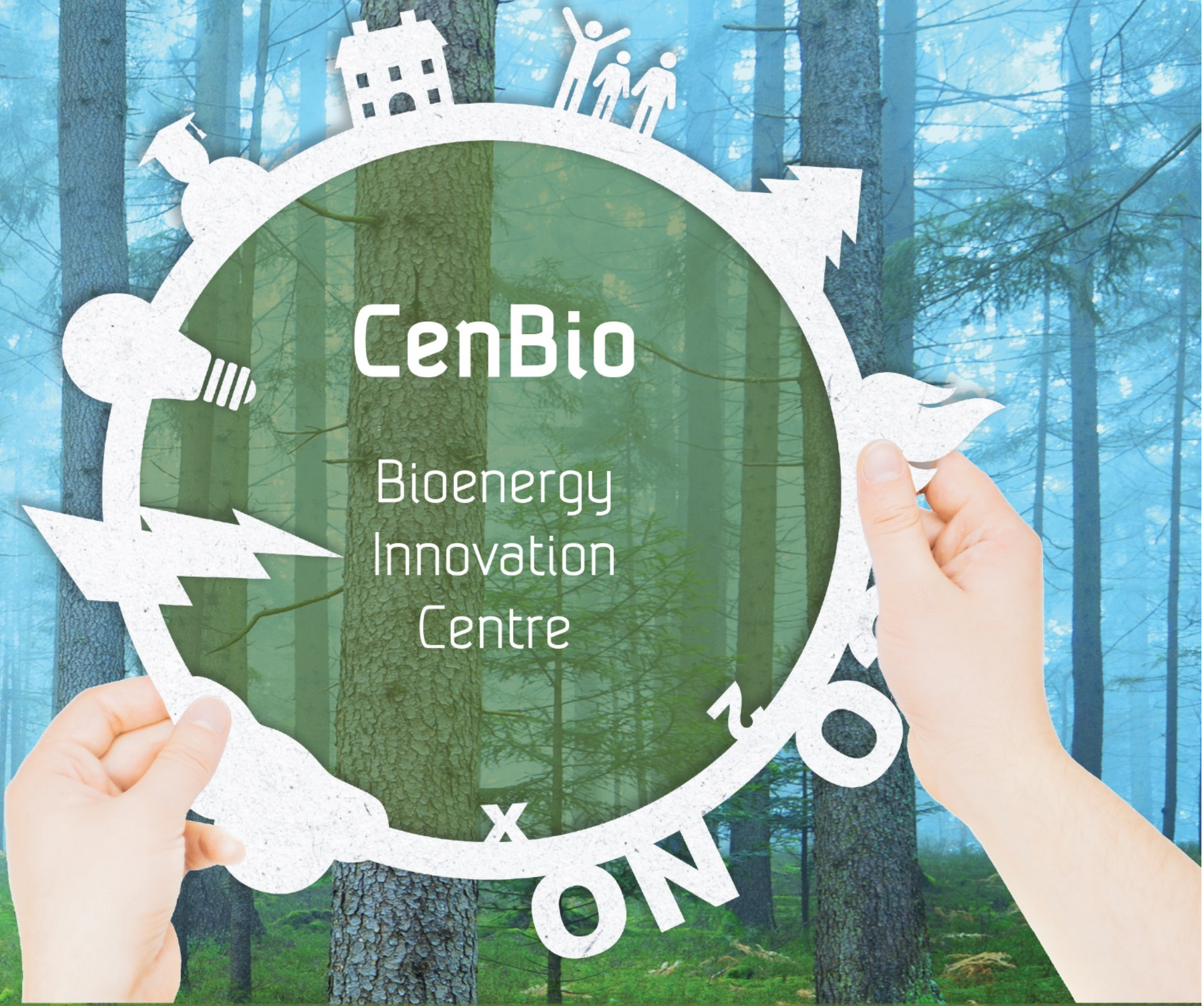
Annual Report 2015



CenBio

Bioenergy
Innovation
Centre

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

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/

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

CenBio Bioenergy Innovation Centre

www.CenBio.no

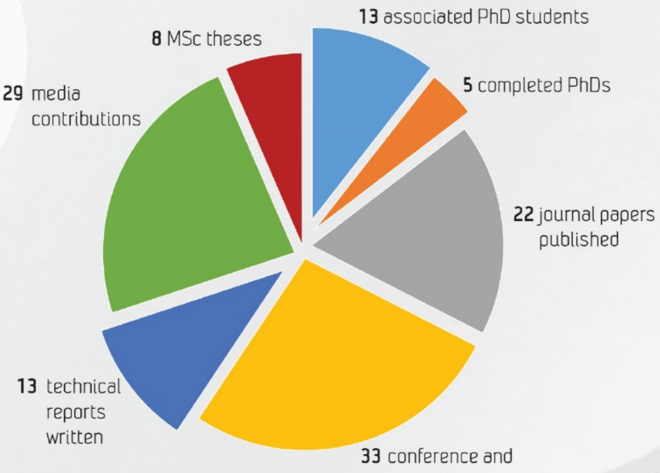
CenBio

Bioenergy Innovation Centre

2015 in numbers

INNOVATIONS

- 11 implemented by 2015
- 22 potential in progress
- 4 about to be finalized



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Bioenergy Innovation Centre

Annual Report 2015

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

Editorial staff at SINTEF Energi AS *(SINTEF Energy Research)*: Line Rydså, Einar Jordanger
Cover: Shutterstock/Astrid B. Lundquist

Abbreviations

List of abbreviations frequently used in this report

AB	Advisory Board
AWP2016	Annual Work Plan 2016
BIA	Bioenergy Innovation Award
CFD	Computational Fluid Dynamics
CHP	Combined Heat & Power
CMT	Centre Management Team
EB	Executive Board
EUBCE	European Biomass Conference & Exhibition
FME	Centre for Environment-Friendly Energy Research (Forskningssenter for Miljøvennlig Energi)
GA	General Assembly
H2020	Horizon 2020 (EU research and innovation framework programme 2014-2020)
KPN	Competence Project with User Involvement (Kompetanseprosjekt for næringslivet)
LCA	Life Cycle Assessment
NFLI	Norwegian Forest and Landscape Institute
NIBIO	Norwegian Institute of Bioeconomy Research (Norsk Institutt for Bioøkonomi)
NMBU	Norwegian University of Life Sciences (Norges miljø- og biovitenskapelige universitet)
NTNU	Norwegian University of Science and Technology (Norge teknisk-naturvitenskapelige universitet)
RCN	The Research Council of Norway
R&D	Research & Development
SA	Scientific Advisor
SP	Sub-project
SET Plan	Strategic Energy Technology Plan
WBS	Work Breakdown Structure
WP	Work Package
WtE	Waste-to-Energy

Editorial

Marie Bysveen

Centre Coordinator

SINTEF Energi AS

Coordinating Institution
(Photo: Gry Karin Stimo)

Odd Jarle Skjelhaugen

Deputy Centre Coordinator

NMBU - Norges miljø- og biovitenskapelige universitet
Host Institution
(Photo: Signe Beate Skjelhaugen)

2015 – Focus on the scientific excellence and increasing CenBio's visibility

In 2015 it has been important for CenBio to continue with its excellent research, and at the same time start planning for the centre to come at its end in 2016/2017.

We are proud of CenBio's track record when it comes to publications and dissemination. The full overview is given elsewhere in this report, but we want to highlight the number of joint publications between research partners and user partners (Figure 5), where our user partners are co-authors in four out of the eleven CenBio-publications resulting from internal collaborations in 2015.

In order to increase CenBio's visibility internationally, CenBio has in 2015 chosen to send a delegation to the 24th European Biomass Conference & Exhibition (EUBCE 2016) on 6-9 June 2016:

- 24 abstracts were sent from CenBio members
- One of our researchers, Francesco Cherubini (NTNU) has been especially distinguished by being offered a spot in a plenary session
- Seven other abstracts were accepted as oral presentations, and 16 as visual poster presentations
- Our presentations are covering the whole CenBio value chain, and all sub-projects are represented
- CenBio will also participate with a stand in the Exhibition area, and a workshop (side event)

A different international aspect is that the EU started to update the EU Strategic Energy Technology (SET) Plan in 2015. CenBio has chosen to organise a workshop in Brussels in 2016 to provide input for the update of the part of the SET Plan concerning bioenergy and biofuels.

In order to disseminate the work performed in CenBio at the national level, CenBio performed these activities in 2015:

- The Foresight process was a major activity in 2014, involving 36 people in the process of scenario development during three workshops. The Foresight report was finalised in September 2014, and it was presented to Energi21 in March 2015, and at a lunch seminar at NVE in June.
- Two of the board members of CenBio, Petter Røkke (SINTEF ER) and Øystein Johnsen (NMBU), contributed with viewpoints to Energimeldingen (Norwegian government work on energy politics). Petter Røkke presented in December CenBio's views on the three important topics; utilisation of biomass, bioenergy and biofuels, where the he emphasised the Centre's desire for a clear prioritisation of research and development.

Finally, we would like to mention the new FME application that has been submitted with NMBU as host and Stiftelsen SINTEF as the centre manager. The application have more R&D partners than in CenBio, and it has many international partners. The research focus is on biofuels, and less on stationary bioenergy compared to CenBio.

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.

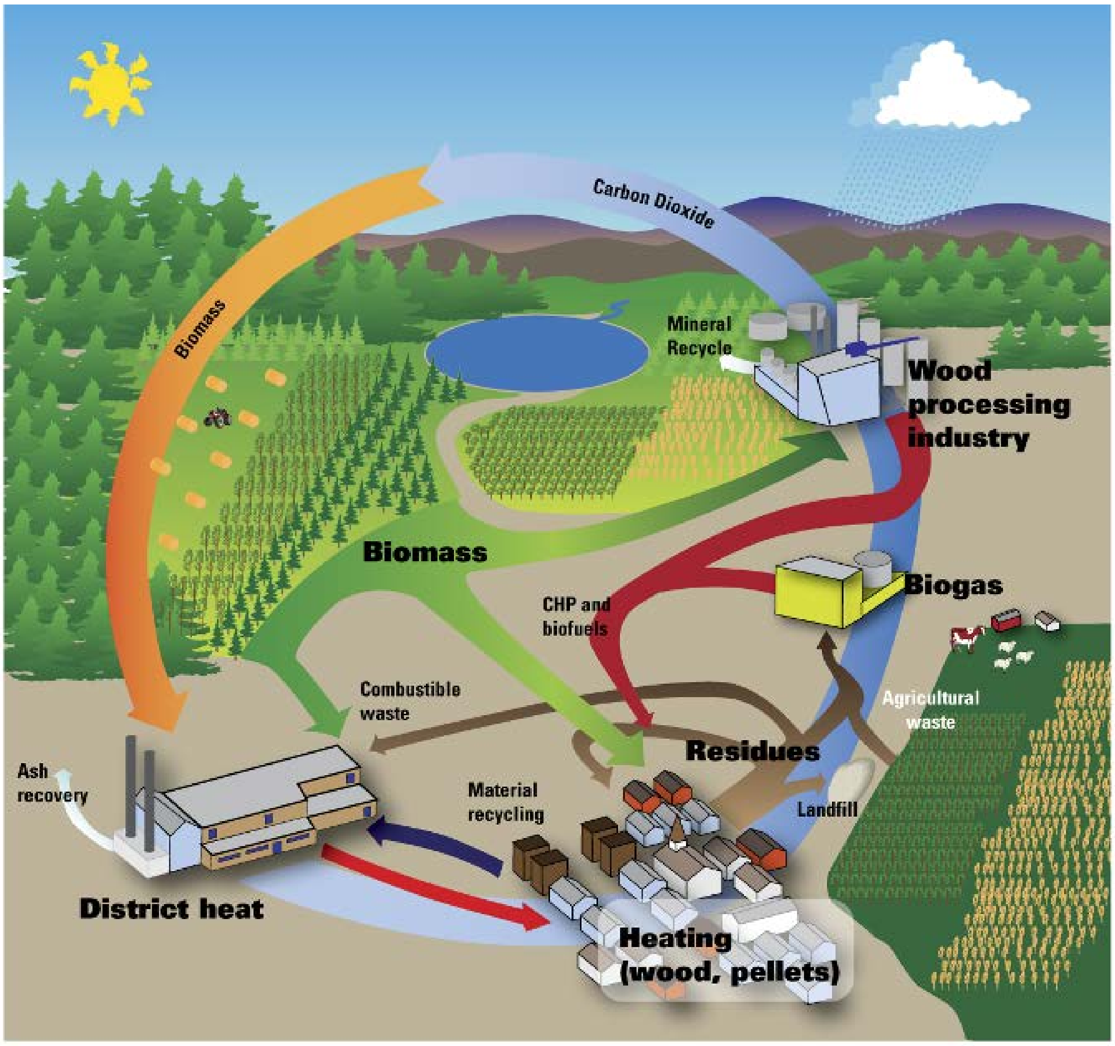


Figure 1: CenBio scope.

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 2016

The Annual Work plan (AWP) 2016 was delivered to the Research Council of Norway (RCN) on 31 December 2015. The work with AWP2016 started with EB in June approving the timeline for writing the work plan, followed by the board giving guidelines for preparing the document. After summer, the work was continued with discussions at CMT level, before the formal start of writing the AWP2016 was initiated with the SP-leaders communicating to user partners and Scientific Advisors (SA) in September. After collecting the inputs and a quick check by the centre management, the AWP2016 was a major topic of the CenBio Strategic Day on 29 October. Comments made during the Strategic Day gave basis for an internal improvement, and a draft was sent to the user partners in November, before it was approved by EB in December.

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 Energi AS

(Photo: Gry Karin Stimo)

The coordination of CenBio in 2015 still involved implementation of recommendations from the midterm evaluation in 2013, as well as further recommendations from the Executive Board (EB). Thus, much of the coordination of CenBio in 2015 have been concentrated around continuing the successful activities in 2014:

- The traditional **CenBio Days** was arranged over three days in March 2015. The event gathered 61 participants. The two new features that were added to this year's programme broadened the scope of the CenBio Days. A Young researcher's breakfast was organised to get their viewpoint on how we best include PhDs and young researchers in CenBio. Secondly, the programme included presentations from the Advisory Board (AB) on "Bioenergy in the rest of the world", as seen by the AB members. The General Assembly (GA) met also during the CenBio Days 2015.

- The new Advisory Board (AB) was established during 2014, and consists of four international experts proposed by EB members. For the operational year of 2015 they used their mandate to contribute to the Annual Work Plan 2016 (AWP2016), and they were largely involved at the CenBio Days 2015, giving viewpoints on important keys to bioenergy development, and synergies between work performed in CenBio and other European countries. In this manner, the AB members definitely fulfilled their purpose of providing unbiased advice to the EB about the relevance and quality of the activities planned and performed in CenBio, as well as future bioenergy research needs post-CenBio.

- The **CenBio Strategic Days** have earlier been organised in 2013 and 2014, and was this year organised over two days in October 2015, gathering 28 participants in total. The first day provided the participants with a tour at two facilities in Trondheim, the SINTEF Energy Lab, and the Statkraft Varme plant at Heimdal. The main activity the second day was to discuss and prioritise the proposed activities for 2016. Furthermore, achievements vs. expectations for the individual CenBio sub-projects were discussed.

The coordination in 2015 also included to start planning for 2016, the eighth and final full operating year of CenBio. The EB agreed in 2015 that CenBio Days in 2016 shall be omitted and rather explore the opportunity to hold or participate in an international conference. The following decisions have been made:

- The AB stated that CenBio has many interesting results that should be presented internationally. The EB agreed that CenBio should increase its visibility by concentrating presentations at conferences by sending a delegation to the 24th European Biomass Conference & Exhibition (EUBCE 2016), the largest and most scientifically diverse bioenergy conference in Europe. Towards the end of 2015 we received the news that the 24 abstracts from CenBio were accepted as oral presentations or posters.

- Towards the end of 2015 we produced a list of Master Theses within the bioenergy field finalised so far during the CenBio period. The list with links to the theses is uploaded to www.CenBio.no under Publications.

- CenBio will organise a final conference in early 2017 to mark its end.

Finally, recent developments in the CenBio consortium should be mentioned. Bioforsk and NFLI has merged into NIBIO, and Hafslund Varme AS has replaced Hafslund ASA. More details can be found in the next sections of this report.

Partners

Initially, 26 partners took part in CenBio. Norges miljø- og biovitenskapelige universitet (NMBU) is host institution and SINTEF Energi AS 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). Hafslund ASA has left CenBio as of 1 January 2016. Hafslund Varme AS replaced Hafslund ASA.

The research partners Bioforsk and Norwegian Forest and Landscape Institute (NFLI) merged in 2015 into NIBIO – Norwegian Institute of Bioeconomy Research. Since NIBIO was registered under the same number as Bioforsk was registered the merge did not require any legal changes on the Consortium Agreement. The old NFLI is now termed Nibio-SOL in CenBio, and the other is named Nibio-Bioforsk. This is done to easier keep track of individual commitments to budget and work performed in the rest of the centre project period.

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
- Nibio-Bioforsk
- Nibio-SOL (Skog og Landskap) – also referred to as Norwegian Forest and Landscape Institute (NFLI) in this report
- SINTEF Foundation (Materials and Chemistry)
- Vattenfall AB (Sweden)

User partners

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

- Akershus Energi AS
- Norges Skogeierforbund
- Hafslund ASA (Hafslund Varme AS from 1 Jan 2016)
- 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 (2015), as defined in the Consortium Agreement is shown in Figure 3.

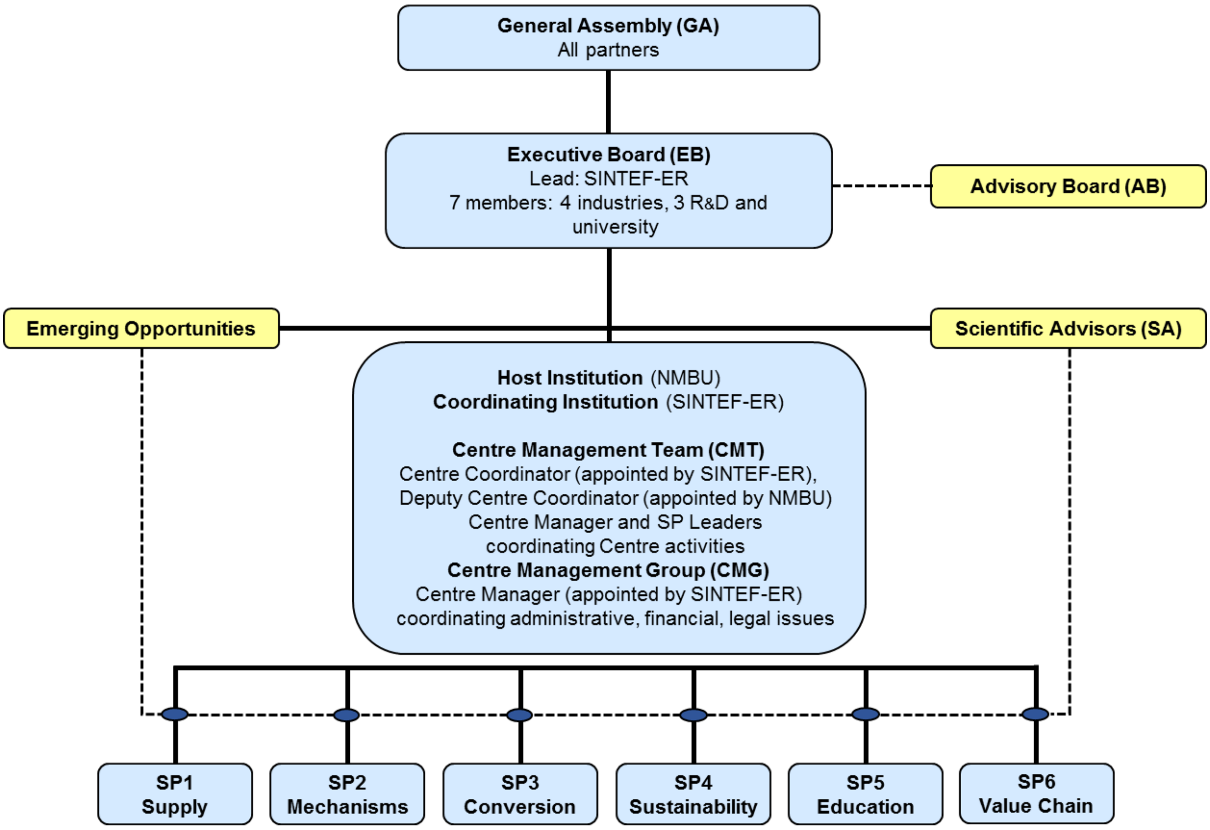


Figure 3: CenBio Governance Structure. SP stands for sub-project.

The Executive Board (EB) consists of seven members, three representing the Research partners and four from the User partners. The Coordinating organisation (SINTEF-ER) appoints the chairperson. Eilif Due replaced Erik A. Dahl after the General Assembly meeting 18 March 2015.

Table 1: Executive Board members, 2015.

Position	Name	Affiliation
Chairperson	**Petter Røkke**	02 SINTEF-ER
EB Member (Research partner)	**Olav Bolland**	03 NTNU
«	**Øystein Johnsen**	01 NMBU
EB member (User partner)	**Erik A. Dahl / Eilif Due**	09 SKOGEIER
«	**Morten Fossum**	13 STATKRAFT
«	**Hans Olav Midtbust**	22 ENERGOS
«	**Pål Jahre Nilsen**	23 CAMBI

The General Assembly (GA) consists of one representative from all partners, and meets at least once a year (usually during the CenBio Days). Egil Evensen was elected as new Chairperson at the GA meeting.

Table 2: General Assembly members, 2015.

Position	Name	Affiliation
Chairperson	**Gudbrand Kvaal/Egil Evensen**	09 SKOGEIER/13 STATRAFT
GA Member (Research partner)	**Ragnhild Solheim**	01 NMBU
«	**Petter E. Røkke**	02 SINTEF-ER
«	**Olav Bolland**	03 NTNU
«	**Olav Arne Bævre**	04 NIBIO-BIOFORSK
«	**Arne Bardalen**	05 NIBIO-SOL
«	**Rune Bredesen**	06 SINTEF-MC
«	**Åsa Astervik**	07 VRD
GA Member (User partner)	**Frank Sagvik**	08 AKERSHUS
«	**Jon Iver Bakken**	12 HAFSLUND
«	**Morten Fossum**	13 STATKRAFT
«	**Jonny Stuen**	19 EGE
«	**Christer Forsberg**	21 VHN
«	**Hans Olav Midtbust**	22 ENERGOS
«	**Pål Jahre Nilsen**	23 CAMBI
«	**Tom J. Berglind**	24 JØTUL
«	**Egbert van de Schootbrugge**	26 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. Number of CMT meetings per year is approximately 10.

Table 3: Centre Management Team.

Position	Name	Affiliation
Centre Coordinator	**Marie Bysveen**	02 SINTEF-ER
Deputy Centre Coordinator	**Odd Jarle Skjelhaugen**	01 NMBU
Centre Manager	**Einar Jordanger**	02 SINTEF-ER
	Alexis Sevault/Line Rydså	02 SINTEF-ER
SP1 Biomass Supply and Residue Utilization	**Simen Gjølsjø**	05 NIBIO-SOL
SP2 Conversion Mechanisms	**Michaël Becidan**	02 SINTEF-ER
SP3 Conversion Technologies and Emissions	**Øyvind Skreiberg**	02 SINTEF-ER
SP4 Sustainability Analysis	**Birger Solberg/ Per Kristian Rørstad**	01 NMBU
SP5 Knowledge Transfer and Innovation	**Terese Løvås**	03 NTNU
SP6 Value Chain Assessment	**Anders H. Strømman/ Francesco Cherubini**	03 NTNU

Scientific Advisors (SA) were appointed in 2010, one for each of the sub-projects SP1-4. The four Scientific Advisors are shown in Table 4. Mikko Hupa had to resign from his SA position since he took over as rector at Åbo. In October 2015 we received the sad news that Michael J. Antal Jr. passed away. He participated once a year at the CenBio Days, and his contributions were valuable not only for SP2 and SP3 but also his general advices on future bioenergy research were appreciated.

Table 4: Scientific Advisors.

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

An **Advisory Board (AB)** was established in 2014 with the purpose of providing unbiased advice to the EB about the relevance and quality of the activities planned and performed in CenBio, as well as future bioenergy research needs post-CenBio.

Table 5: Advisory Board.

Name	Affiliation
Pat Howes	*Ricardo Energy & Environment (UK)*
Arto Timperi	*Comatec (Finland)*
Claes Tullin	*SP Technical Research Institute of Sweden (Sweden)*
Marcel van Berlo	*T&S (Netherlands)*

Work Breakdown Structure (WBS)

The technical activities within CenBio are organised 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.

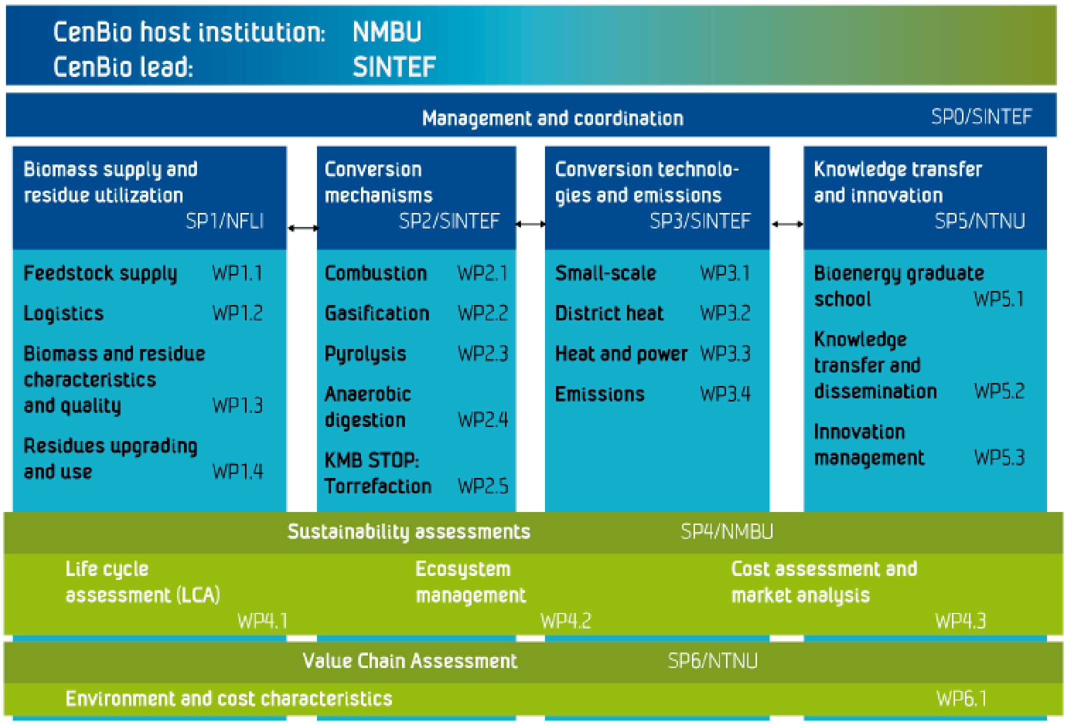


Figure 4: Work Breakdown Structure.

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 Energi AS. , Internal collaboration is especially important between SP6 and other sub-projects in CenBio. In 2015, there have also been an extensive collaboration between SP1, SP2 and SP3 on ash activities.

The number and nature of internal collaborations leading to peer-reviewed publications (both journal and conference) are shown in Figure 5. Up to and counting 2015, the total number is 95 internal collaborations leading to publications.

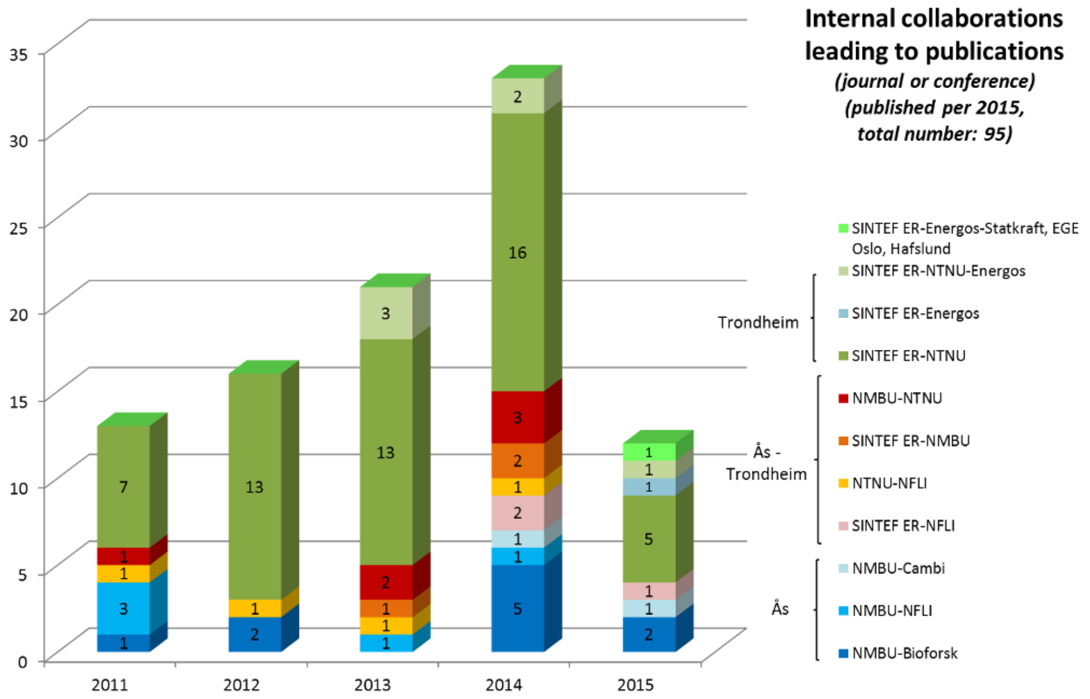


Figure 5: CenBio internal collaborations leading to peer-reviewed publications (journal or conference).

The User partners also contribute with in-kind research. In 2015 we see that four out of the eleven internal collaborations leading to publications had industry partners as co-authors, namely from Energos, Statkraft Varme, EGE Oslo, Hafslund and Cambi. Some of these publications are further described in the individual sub-project sections elsewhere in this report.

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' activity in each respective WP; the draft is discussed either in meetings where interested partners participate or in direct dialogue with representatives from the User partners.

CenBio Days and Strategic Days

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 2015, the CenBio Days took place at Hell just outside Trondheim, on 17-19 March. This year's programme included presentations from selected CenBio researchers, as well as invited external speakers covering the topic of "Challenges with legal aspects and standardisation". A Young researcher's breakfast was organised to get their viewpoint on how we best include PhDs and young researchers in CenBio. The Advisory Board (AB) members gave each a presentation on "Bioenergy in the rest of the world", as seen by the AB members.

Since 2013, a second yearly meeting is organised with all the partners around October, with a special focus on the next Annual Work Plan. The CenBio Strategic Days were this year organised on 28-29 October 2015 in Trondheim. The first day provided the participants with a tour at two facilities in Trondheim, the SINTEF Energy Lab, and the Statkraft Varme plant at Heimdal (see Figure 6). This event, which first happened in 2013, enabled to discuss various topics of strategical importance for the Centre:

- Inputs for the Annual Work Plan 2016
- CenBio results: Achievements vs. expectations for the various sub-projects
- Value chain assessment (SP6): summary of results

Figure 6: Members of CenBio visiting the Statkraft Varme plant at Heimdal during the CenBio Strategic Days 2015. (Photo: CenBio)

Management and Coordination

General

The overall coordination activities are organised within a separate sub-project (SP0) - Management and Coordination. During 2015, the main activities consisted in reporting costs and progress, arranging coordination meetings, and coordinating the planning of collective participation in an international event (EUBCE 2016). Management within each SP or WP is the responsibility of respective SP- and WP leaders. In addition to those usual tasks, SP0 also organised 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. The overall structure of the CenBio eRoom was described in the Annual Report 2011.

Meetings

The Centre Management Team had ten meetings in 2015. The Executive Board had five meetings, in March, June, August, October and December, and the General Assembly met on 18 March at Hell, during the CenBio Days. Most CMT meetings are arranged as teleconferences using eRoom for sharing documents and information.

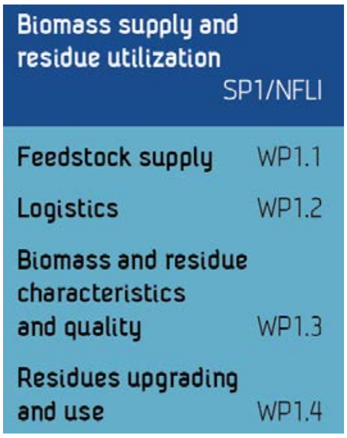
Deliverables list and Publication database

In order to keep track of planned deliverables including journal papers for review an Excel workbook is established (in Folder 060 in the eRoom). 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 (in Folder 065). Status is indicated by one of these stages: planned, in progress, submitted, accepted, in press, published.

Research Activities

Biomass Supply and Residue Utilization – SP1



WBS of SP1.

Simen Gjølsjø

Leader of Biomass Supply and Residue Utilization

Norwegian Institute of Bioeconomy

(Photo: Lars Sandved Dalen)

SP1 focuses on analysing the current biomass availability, as well as analysing the long-term production potential for biomass from forested areas for energy purposes.

An important activity in SP1 has this year been to improve the biomass estimation in Norway. The work has focused on the development of new methods and models that can be used in inventories for assessing forest biomass, including roots, stem and branches. Very little has previously been done on assessing the biomass estimation of roots and branches. This has been the topic for Aaron Smith's dissertation in 2015. The main objective of his work was to improve individual tree biomass estimation both aboveground and belowground. This work has made a significant achievement facilitating accurate estimation of improvement to assess the biomass stock in Norway, both below ground and above ground.

Some of the forest in Norway has harvesting restrictions, and researchers have worked with methods and tools that may support forest managers to minimise economic losses and to handle and avoid conflicts in recreational areas. Issues related to cost-efficient harvesting operations have also been covered. Clustering of harvesting sites is important to reduce the fixed-costs and increase the net present value.

Chipping at forest roadside landing and consecutive woodchip transport is a common step in the supply chain. By studying 13 chipping contractors in Norway, the conclusion from practitioners in the field trials indicates substantial operational delays originating from poor working conditions or work organisation. The time consumption for the chipper varied between 0.7 and 1.6 minutes per m^3 loose and the utilization varied between 35% and 70%. Poor terminal functionality was mostly related to limited flat area of sufficient bearing capacity on the terminal.

The chemical compositions and fusion behaviours of ashes from stem wood, bark, base branch and top branch have been characterised. Compared to other three ashes, top branch ash contains considerably high content of K and P, and is rich in Ca and Si as well. Analyses on four fuel types indicated that melting of them might start in the temperatures range of 930-960 °C. In comparison to ash originated from stem wood, analyses confirm that the ashes from stem bark, base branch and top branch have higher sintering tendency. Top branch ash contains substantially high concentration of K and P elements. These two typical mobile elements in plants are often found in twigs containing a large amount of young and biologically active tissues.

Moisture content is one of the most important quality parameters of forest biomass used for bioenergy. The standard method currently used for determining moisture content involves oven drying at 105 °C until stable weight is reached (oven-drying method). For buyers of biomass, a disadvantage of the oven-drying method is that it takes at least 24 hours before the moisture content of the delivered biomass is determined. The accuracy for frozen and non-frozen chips have been tested with the near infrared spectroscopy. The tests were successful and the method was approved by Virkesmätningen (VMK) in Sweden in December 2015.

Feedstock supply – WP1.1

In work package WP1.1. Feedstock supply, the activities in 2015 were divided into two main parts. The first part focused on the development of new methods and models that can be used in inventories for assessing forest biomass. The second part dealt with bio-economic optimisation methods handling linkages between silvicultural treatments, economic behaviour, sustainability criteria and biomass supply in forest decision-support tools.

Methods and models for assessment of forest biomass

Aaron Smith, PhD student at NMBU, but funded by CenBio through Norwegian Institute of Bioeconomy Research (NIBIO), defended successfully his thesis[1] on October 22, 2015. The main objective of the thesis was to improve individual tree biomass estimation in order to improve biomass estimation in Norway. Aaron's advisors were Andreas Brunner (NMBU), Rasmus Astrup, Aksel Granhus, and Halvor Solheim (all NIBIO).

Figure 7. Aaron Smith removing dirt and debris from a root system in order to estimate belowground birch biomass.

(Photo: Marketa Stenova)

In one of the paper in the thesis,[2] Smith studied tree root architecture. The accurate characterisation of three-dimensional (3D) root architecture, volume, and biomass is important for a wide variety of applications in forest ecology and to understand tree and soil stability better. In this study, 13 recently harvested Norway spruce root systems were mechanically pulled from the soil, cleaned, and their volumes were measured by displacement, as you can see in Figure 7.

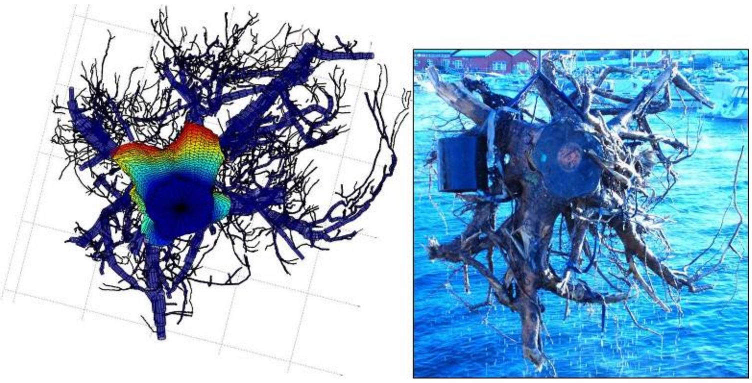


Figure 8: Root system images.

The root systems were suspended, scanned from three different angles, and the root surfaces from the co-registered point clouds were modelled with the 3D Quantitative Structure Model to determine root architecture and volume (see Figure 8). The modelling procedure facilitated the rapid derivation of root volume, diameters, break point diameters, linear root length, cumulative percentages, and root fraction counts. The modelled root systems underestimated root system volume by 4.4%.

In another paper[3], Smith developed belowground birch biomass functions. Obtaining accurate estimates of national belowground and whole tree biomass is important to better understand the global carbon cycle and to quantify biomass stocks and changes. Allometric birch biomass functions were derived from 67 trees for belowground and whole tree biomass using diameter at breast height and height as the independent variables. Comparisons with existing belowground birch biomass functions from Fennoscandia indicated considerable differences in estimates between existing functions. The derived data set for belowground birch biomass is the largest in Fennoscandia and the developed functions are likely the best available for estimating national birch biomass stock and stock change in Norway.

Bio-economic optimisation

Forest management is a complex task where conflicting interests often need to be handled. The development of methods and tools that may support forest managers in their decision-making is therefore important. Paulo Borges has dealt with different aspects of forest management over the past year. For certain forest areas in Norway law regulations do not allow large clear cuttings. One of Borges' studies[4] therefore focused on solving methods related to maximum opening areas in harvest operations. The main objective was to develop methods minimising profitability losses because of such restrictions. In another paper[5], 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 face multiple challenges in their management. Borges studied the effects of different environmentally oriented restrictions on available timber and biomass quantities from the municipality forest. Results showed that the profitability might be reduced by up 20% because of the restrictions. Still, however, a supply of 20-30 GWh annual energy from harvest residues can be provided from the municipality forest.

A third study by Borges focused on cost-efficient harvest operations.[6] In strategic forest level planning, the harvest levels are typically obtained by maximising net present value (NPV) of the forest area. The resulting harvests are then also typically scattered over the area. The fixed costs, however, i.e. costs related to transferring the machines to the harvest site, waiting time for the machinery and workers due to the transfer, delineation of the harvest sites and administrative work required for each harvest site, will in such cases be high. In this study, clustering of harvest sites was carried out by minimising the total fixed costs for all harvest sites. The results showed, as expected, that when the fixed cost increased it was optimal to make larger and larger harvest clusters. At the same time, however, the clustering also affects the treatments to be carried out by making it profitable, for example, to harvest at lower or higher ages than the optimal rotation age settled when fixed costs is not considered.

Logistic – WP1.2

The work in WP1.2 has concentrated on temporary chipping terminals at roadside landings. The low bulk density of low-grade biomass assortments such as logging residues and whole trees limits the feasibility of transporting the material unprocessed. Chipping at forest roadside landing and consecutive woodchip transport is therefore a common step in this supply chain. The chip supply system deviates from the conventional roundwood supply in several aspects, and the interaction between equipment and work methods and the roadside landing should therefore be of interest. Forest roads are designed having the characteristics of the roundwood supply chain in mind. A good understanding of the physical requirements for a temporary roadside chipping terminal, and how these requirements are related to different equipment and work methods, is necessary both at tactical and operational planning, and supply chain configuration. To illuminate this issue a survey among practitioners in Norway were done to answer the following questions:

1) What equipment and work methods are more or less common for chipping at temporary forest landings / terminals in Norway, and how optimal are these operational configurations?
2) What are their requirements and wishes for the physical layout of a temporary roadside terminal?
3) How is the utilization of the different supply chain elements affected by the terminals?

Fourteen sites were visited in the survey. The supply configurations studied here were "hot" systems, where the processing and transport units are closely dependent of each other. In such set ups the capacity ratio between the chipping and transport govern the achievable utilization for both units involved. In most cases the capacity of the transport unit(s) were lower than the chipper, but still the utilization of the transport units varied between 60 and 90 %.

In Figure 9, Plot 1 shows the chip transport productivity versus modelled productivity. The straight line is indicating where the achieved productivity would equal the capacity. Plot 2 and 3 shows the utilization of the transport capacity versus the capacity ratio between the chip transport unit(s) and the chipper (2) and versus the terminal functionality (3). The solid line in plot 2 indicate the maximum achievable utilization according to the capacity ratio between transport and chipping.

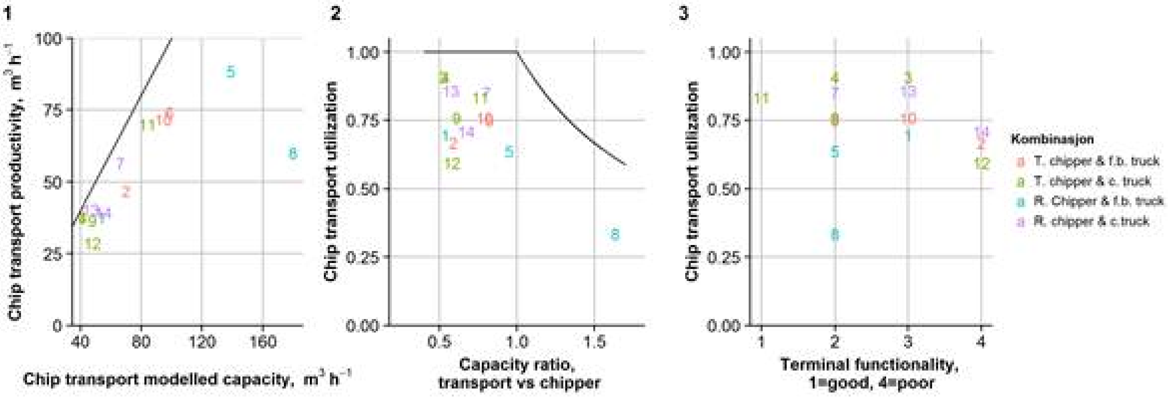


Figure 9. Results from study of chipping logistics: 1) chip transport productivity, 2) and 3) utilisation of the transport capacity.

In Figure 10, the first plot (1) shows the total time consumption of the chipper per unit bulk volume versus estimated chipping capacity. The solid line illustrates the time consumption equivalent for the capacity, i.e. the time consumption if the chipper achieved maximum utilization. Plot 2 shows the chipper utilization versus the capacity ratio between the transport unit(s) and the chipper. Here the solid line shows the maximum chipper utilization that would be achievable for each capacity ratio. Plot 3 shows the chipper utilization versus the terminal functionality score.

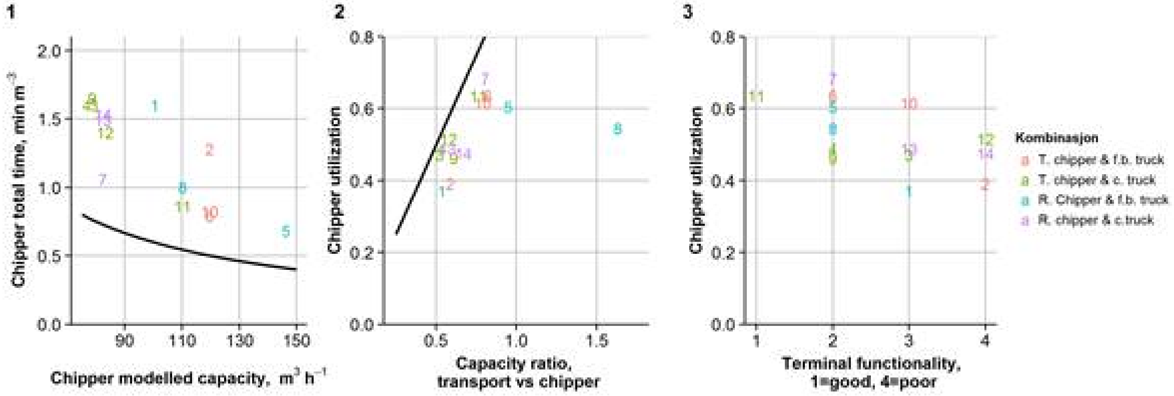


Figure 10. Utilization of chipper: 1) time consumption, 2) and 3) chipper utilization.

Biomass and residue characteristics and quality – WP1.3

Considerable variations of qualitative properties between stem wood, stem bark and branch wood of Scots pine forest residues vertically along the stem very observed. In average, the highest basic density showed to have branch wood, lower stem bark and the lowest one stem wood. The basic density of stem wood was higher in the lower part of stem, vertically decreasing to approximately towards to tree top (Table 6). Contrary, the basic density of stem bark decreased to 40 % height and then slightly increasing again towards the top. Branch wood had a higher basic density than stem wood. The basic density of branch wood decreased in the direction from the branch basis to its top. There was not found relationship between basic density of stem wood, stem bark and branches and the site index quality of selected forest stands.

Table 6. Average values of basic density (kg/m^3) and standard deviations of Scots pine stem wood and stem bark along the tree trunk towards the top.

Site	**Site index**	**Stem wood**						**Stem bark**					
		Tree height (%)						**Tree height (%)**					
		Base	**BH**	**20**	**40**	**60**	**80**	**Base**	**BH**	**20**	**40**	**60**	**80**
S1 Hobøl	**17**	418.3 (43.5)	408.3 (6.0)	410.6 (36.5)	398.0 (18.2)	369.1 (3.4)	337.2 (19.6)	320.3 (15.2)	313.3 (11.2)	345.3 (5.5)	319.2 (3.6)	321.8 (2.5)	364.2 (2.1)
S2 Hobøl	**11**	416.6 (44.2)	398.4 (51.7)	378.9 (37.3)	331.4 (17.6)	317.7 (18.8)	308.2 (67.1)	296.9 (15.1)	298.1 (9.9)	288.0 (3.3)	265.1 (2.4)	299.4 (2.5)	330.1 (1.9)

Bark proportion and bark thickens were highly linear to the tree height (Figure 11). Bark proportion and thickness may be relevant aspects for the utilization of biomass feedstock from Scots pine forest raw material.

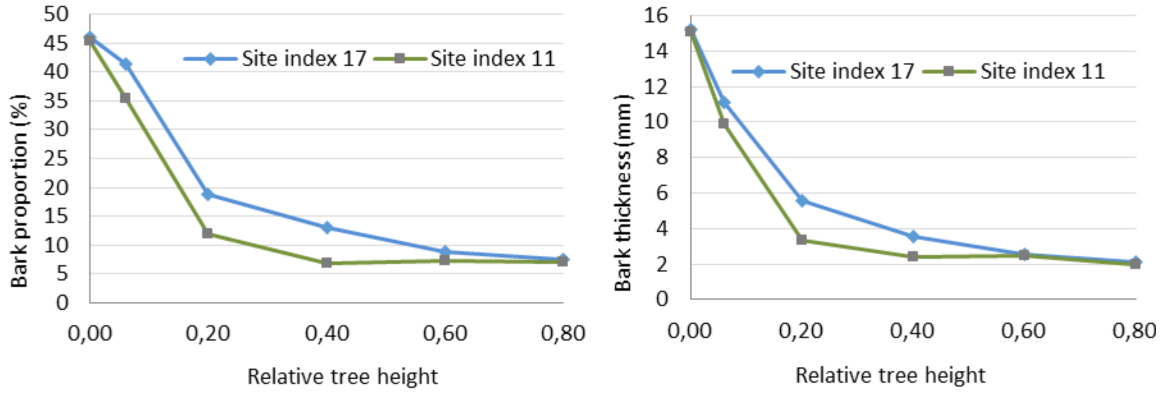


Figure 11. Trend in mean values of bark proportion (left) and bark thickness (right) of Scots pine. Site index = productivity class (how fast the forest grows).

The chemical compositions and fusion behaviours of ashes from stem wood, bark, base branch and top branch were characterised with ICP-OES, STA and SEM-EDX. Compared to other three ashes, top branch ash contains considerably high content of K and P, and is rich in Ca and Si as well (Figure 12). STA analyses on four kinds of fuels indicate that melting of them might start in the temperatures range from 930 °C to 960 °C. In comparison to ash originated from stem wood, SEM-EDX analyses confirm that the ashes from stem bark, base branch and top branch have high sintering tendency. Top branch ash contains substantially high concentration of K and P elements. These two typical mobile elements in plants are often found in twigs containing a large amount of young and biologically active tissues. Abundance of K and P, together with Ca, may cause formation of low temperature melting K-Ca-phosphates, partially explaining high sintering tendency of the top branch ash.

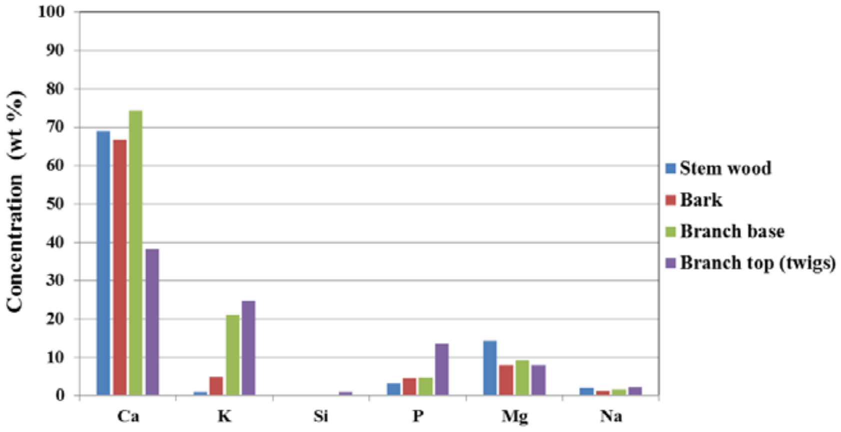


Figure 12. Average elemental composition in the formed ashes (presented on a carbon- and oxygen-free basis. Forest biomass moisture measurements in frozen conditions.

Forest biomass supply to heating plants is subject to diverse constraints in the supply chain, from harvest to transport logistics, and not to forget all the challenges related to storage and preserving or increasing biomass quality before it is used for bioenergy. Winter biomass recovery operations provide for most of the yearly supply needs of heating plants in Scandinavia and frozen biomass is a very common feedstock delivered.

Moisture content (M) is one of the most important quality parameters of forest biomass used for bioenergy. M strongly influences the net calorific value of the delivered biomass and consequently the price per ton. The standard method currently used for determining M involves oven drying at 105 °C until stable weight is reached (oven-drying method). For buyers of biomass, a disadvantage of the oven-drying method is that it takes at least 24 hours before the M of the delivered biomass is determined. Many heating plants have limited storage space, so it is very likely that sampled biomass loads are fed to the boiler within this 24-hour period. Consequently, the advantages to the boiler operator of knowing the moisture content of the fuel fed to the boiler are lost, and the result is an increased risk of inefficient combustion.

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

Residue upgrading and use – WP1.4

As in previous years the main activities in WP 1.4 are related to the Ph.D. work of Eva Brod «The recycling potential of phosphorus in secondary resources». In 2015 ash and anaerobic digestates from CenBio industry partners have been studied in a broader context to evaluate the recycling potential of phosphorus in secondary resources both from land based and marine based sectors in Norway.

Combining material flow analysis (MFA) and studies on phosphorus plant availability

In traditional material flow analysis (MFA) the total amount of phosphorus in secondary resources is estimated, and the recycling potential is evaluated according to the total P-amount. However, the fertilisation effect of P in secondary resources is often much lower than that of water-soluble mineral P fertiliser. This was confirmed in a study that was partly funded by CenBio, in which the plant available fraction of P in different secondary resources was determined by a bioassay.[7,8] Therefore, in cooperation with a research group of the industrial ecology programme at NTNU, led by prof. Daniel Müller, we developed a method to combine MFA and plant-availability of P from in different secondary P resources. The paper has been submitted to the journal Environmental Science & Technology.[9] Our study showed that there is a large potential for increased P recycling of secondary P resources in Norway, and a potential for drastic reduction in use of mineral P as fertilizer, also when considering plant-availability of P in secondary resources. Although anaerobic digestates and ash has relatively high P use efficiency (PUE),[7] animal manure and fish sludge from aquaculture represent the largest volumes of secondary P resources suitable for fertilizer use.[9]

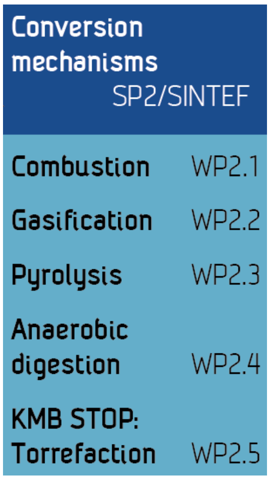
International cooperation: research stay at ETH in Zürich

In the period August 2014-January 2015 Eva Brod had a 6-month stay at ETH in Zürich, Switzerland, and carried out an experiment using ^{33}P radioisotope methods. The results from this experiment confirmed previous papers on P availability of secondary P materials,[7,8] and a paper has been submitted to the special issue “Sustainable Phosphorus” in the journal Frontiers in Nutrition and Environmental Sustainability.[10]

Ph.D. thesis

Eva Brod has now submitted her thesis «Recycling potential of secondary phosphorus resources» for evaluation. One of the main outcomes of the study is a system for predicting the P fertilisation effect of secondary P resources based on chemical analyses. It has been shown that the Norwegian traditional method for characterising P availability of secondary resources (AL-method) did not have any correlation with plant uptake. Therefore, other methods have been recommended for predicting P availability[8] that are presented in a decision tool: If P in the secondary resource in question has been precipitated with Al and/or Fe, Brod recommends predicting the P fertilisation effect based on the total concentration of Al and Fe in the product. This result is based on studies of Øgaard and Brod[11] that have partly been funded by CenBio. Otherwise, P in the secondary resource is mainly present as calcium phosphates of different solubility. The solubility of calcium phosphates is dependent on pH of the target soil. Therefore, one of two extraction methods was recommended, depending on the pH in the target soil. If soil pH <6.5, Brod recommends extraction of P with water. If soil pH >6.5, we recommend predicting the fertilisation effect by the Olsen P method.

Conversion Mechanisms – SP2



WBS of SP2.

Michaël Becidan

Leader of Conversion Mechanisms

SINTEF Energy Research
(Photo: Gry Karin Stimo)

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.

Important aspects to mention from the work in SP2 is the mix of long-term challenges together with short-term "troubleshooting" discussions. The methods used span from experiments in laboratory-scale reactors, advanced measurement equipment and analytical methods, to investigations at full-scale facilities, and additionally modelling as well as desk studies. In 2015 there has been strong involvement of CenBio industry in both work at full-scale plants and in writing articles. Non-CenBio actors have been involved whenever necessary for the benefit of CenBio.

Concrete 2015 achievements in SP2 are:

- Ash deposits collection and advanced analysis at two partners, EGE and Statkraft Varme, in order to propose abatement methods. Two conference articles summarise the main results

- Full-scale bioheat plant measurement campaign to map the concentrations of a number of gaseous species inside the combustion chamber, at different locations and at varying operating conditions in order to better understand formation mechanisms

- CFD modelling activity on the aforementioned plant, where the essential part of the work in 2015 has been on improving the model of the conversion of the fuel bed

- In-depth study of selected ash-forming elements applied to the Energos gasification process using thermodynamic modelling, the main goal being a better control over the corrosion risk

- Study of the population dynamics of biogas reactors at laboratory scale

- Quang-Vu Bach (NTNU) defended his PhD thesis on wet torrefaction in January 2015

Combustion – WP2.1

Measurement campaign and combustion modelling at Statkraft Varme Marienborg

The work in CenBio at the Statkraft Varme Marienborg plant has been performed to better understand and hence improve plant operation. The work has been done as a cooperation between SINTEF Energy Research, NTNU and Statkraft Varme AS, and has consisted of two main activities: measurement campaigns and combustion modelling.

Biomass combustion plants in Norway are facing stricter emission regulations and lower profitability, mostly due to low energy prices. Hence, performance optimisation through improved combustion process control and/or retrofitting becomes very attractive to existing plants. However, the trial and error approach usually applied by the plant operator is time and cost consuming, and offers no guarantee of success. Increased combustion process knowledge on the other hand has the potential to provide the necessary input to improved combustion control strategies, being operational aimed or design/retrofit aimed. The outcome of the improved control strategies can be lower emission levels, improved efficiencies, increased plant capacity or/and reduced maintenance costs.

In this study, a measurement campaign was carried out at a 10 MW grate fired plant burning wood briquettes – the Statkraft Varme Marienborg plant in Trondheim, see schematic picture in Figure 13. The aim of the measurement campaign was to map the concentrations of a number of gaseous species inside the combustion chamber, at different locations and at varying operating conditions. A specially constructed probe was employed to extract gas at different locations close to the fuel bed, in the freeboard and at the combustion chamber exit. A Fourier Transform Infrared Spectrometry (FTIR) instrument was used for gas measurements, including NO_X precursors/intermediates. In addition, a gas chromatographer (GC) quantified the remaining main species as well as provided a validation for some of the FTIR measurements. During the campaign the plant load was varied between 4.5 and 10.5 MW.

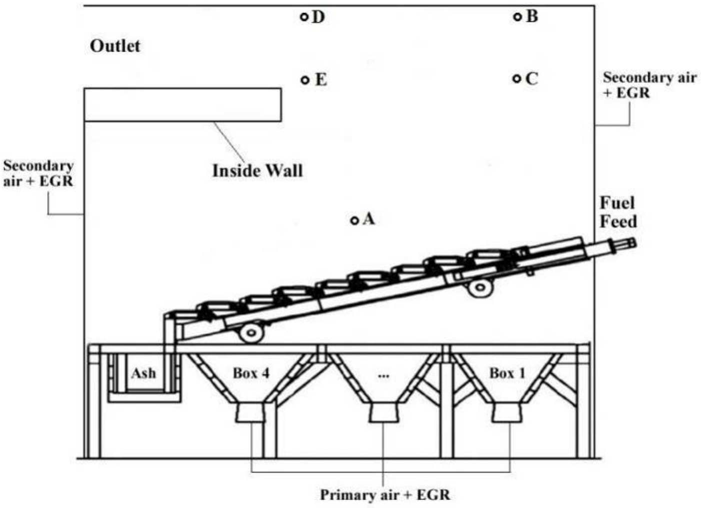


Figure 13: Schematic drawing of the Statkraft Marienborg biomass grate furnace, including measuring ports (A-E).

The measurements taken just above the bed showed high concentration of devolatilisation products. These products increased with increasing thermal input. In addition, NO_X precursors, HCN and NH_3 increased with increasing load. However, the measured ammonia concentration was lower than expected and could be caused by adsorption in the filter unit. Gas measurements were also taken after secondary air injection (positions B and C) and at the outlet of the combustion chamber (positions D and E). For low thermal load, unburnt compounds were still present at position B and at even higher concentrations further inside the boiler (position C). This is reflected by the high CO concentration. Higher thermal input resulted in better combustion efficiency, however the CO concentration still increased when the probe was positioned further into the boiler (positions E and C). NO concentrations at all positions (B, C, D and E) were stable.

Together with continuously measured flue gas concentrations and plant operational data, the measurements provide valuable information for combustion control strategies as well as for validation of modelling approaches, or input to these. Computational Fluid Dynamics (CFD) is the ultimate design tool for bioenergy plant combustion and heat transfer sections, however, cost-effective sub-models need to be developed. NTNU has worked on developing a comprehensive CFD model with the open source software package OpenFOAM including detailed descriptions of the physical processes involved, the NELLI code.[12] OpenFOAM enables full access to sub-models on all levels (particle models, kinetics etc.).

The essential part of the work in 2015 has been on improving the model of the conversion of the fuel bed. Previously a full Eulerian-Lagrangian approach has been used, where each individual biomass particle is tracked throughout the simulations. However, this approach becomes extremely cumbersome when dealing with large sized systems as well as uncertainties about detailed initial conditions for the simulations are restricting reliable results. In order to resolve sufficient details in a computationally inexpensive manner, efforts have now been made to develop a complete new solver in OpenFOAM to enable that the fuel bed can be considered as a continuum and modelled as a porous medium. This will increase the flexibility of NELLI, and broaden the applicability of the code to industrially relevant systems such as commonly used grate fired furnaces. The model will be validated with the measured data obtained from the 10 MW biomass grate furnace at Statkraft's Marienborg biomass combustion plant described previously,[13] and will be presented at the European Biomass Conference and Exhibition (EUBCE) in June 2016.[14] The measurement campaign carried out provides useful data for CFD modelling of the plant, both for modelling of the fuel bed, the freeboard and flue gas emission levels.

Ash deposits – Conference article to IConBM2016

This work on ash deposits has been a cooperation between sub-projects (SP1 and SP2) and several R&D and industry CenBio partners: SINTEF-ER, SINTEF-MC and EGE Oslo. The results from the work was summarised in a conference article sent to IConBM2016.

MSW is a mixture of inhomogeneous materials with large proportions of ash that contains high concentrations of sulphur, chlorine, alkali and alkali earth metals, and minor amounts of heavy metals like lead and zinc. During incineration, these ash-forming elements will volatilise and transform through complex chemical and physical processes, and will be transported together with particles from the fuel bed in the flue gas. These volatiles and fine ash/fuel particles result in formation of deposits on heat transfer surfaces in the convective section of the boiler. Due to further accumulation and sintering of the deposits, the heat transfer from the flue gas to the heat transfer tubes can be significantly reduced, causing reduced energy efficiency of the plant. Additionally, excessive formation of corrosive deposits will also lead to corrosion of heat transfer tubes and will increase maintenance costs (reduce components' lifetime) and unplanned shutdowns. Therefore, detailed characterisation and studies on deposits from MSW incineration plants are critical to understand and predict ash transformation and the related deposits formation process. A picture of the bulk deposits as received is shown in Figure 14.

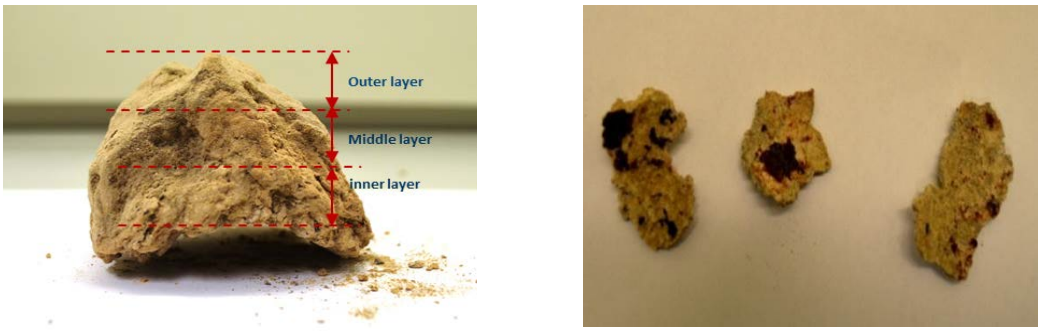


Figure 14. Photos of bulk deposit (left) and inner layer (right).

Chemical and mineralogical compositions of deposits from the EGE Oslo Klemetsrud WtE plant have been characterised (see Figure 15 for analysis results). Ash deposits are analysed via a combination of scanning electron microscopy equipped with energy dispersive X-ray spectroscopy (SEM-EDX), X-ray powder diffraction (XRD) and X-ray fluorescence (XRF). The results show that the deposits formed have a clear-layered structure along the thickness, in terms of density and morphology. The combination of different analytical techniques is also capable of characterising chemical and mineralogical compositions of the collected deposits along the thickness of the deposits. The key ash transformation and chemical reactions involved in deposits formation in this plant are investigated. The primary deposits, mainly melted sulphates and chlorides, initially build on heat transfer tube surfaces and act as a sticking surface to particles and aerosols passing by. The secondary deposits are dominated by calcium sulphates, silicates, and calcium and silicon oxides formed in the combustion chamber. Within the deposits, interactions of different mineralogical phases take place, leading to formation of new chemicals and further sintering of deposits.

Such advanced analysis and characterisation studies are seldom carried out on industrial samples and bring valuable information on the mechanisms at work and the parameters of importance.

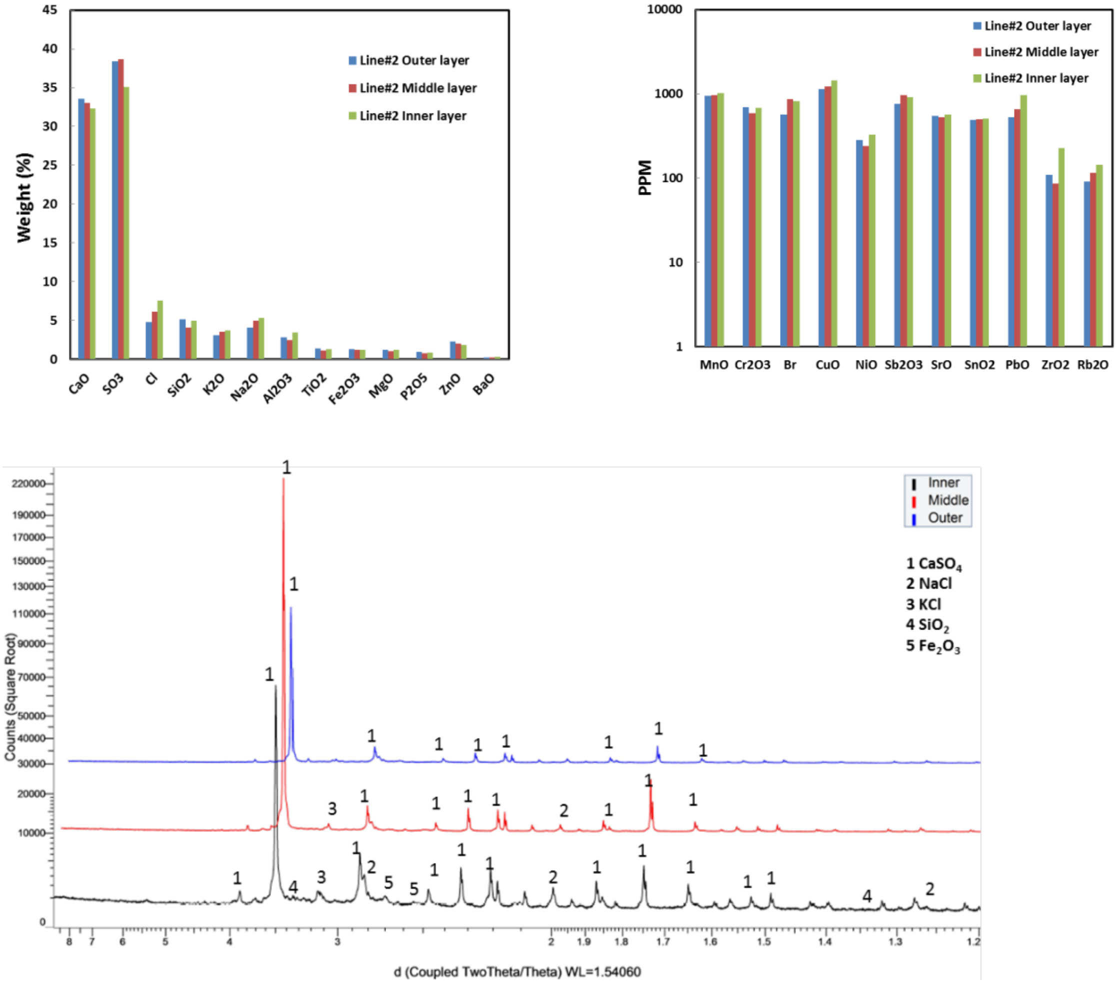


Figure 15. Chemical compositions of different parts of deposit collected from line #2 (top). Mineralogical composition different parts of deposit sample collected from line #2 (bottom).

Ash deposits from Statkraft Varme

In the present work, the chemical and mineralogical compositions of ash deposits collected from the Statkraft Varme Heimdal WtE plant are characterised and evaluated (see also previous section for similar work at EGE Oslo). The ash samples have been collected vertically from bottom to top of the right side wall of the primary combustion chamber. The collected ash samples include ash slag formed in the vicinity of the grate and ash deposits formed on the boiler wall, see Figure 18 for ash and deposit samples.

Ash samples are analysed via X-ray fluorescence (XRF) and a scanning electron microscopy equipped with energy dispersive X-ray spectroscopy (SEM-EDX), in order to obtain both bulk and micro chemical compositions. In addition, mineralogical phases in the ash samples are characterised via X-Ray powder diffraction (XRD).

The slag sample has completely melted into a dense clinker that has a clear layer structure along the thickness. SEM-EDX spot analyses on each layer reveal clear differences in chemical compositions and associations of the detected chemical elements. The ash slag formation process is investigated via a combination of SEM-EDX and mapping analyses on all layers. Analyses of ash deposits collected from different locations showed that they contain mixtures of salts, silicates and oxides formed during combustion of the MSW. However, concentrations of certain elements are different for ash deposits sampled from different locations, indicating partitioning differences during the transportation from bottom to top of the primary combustion chamber. **Accordingly, different final disposal/use methods could be considered for the ash deposits collected from different locations in the plant.**

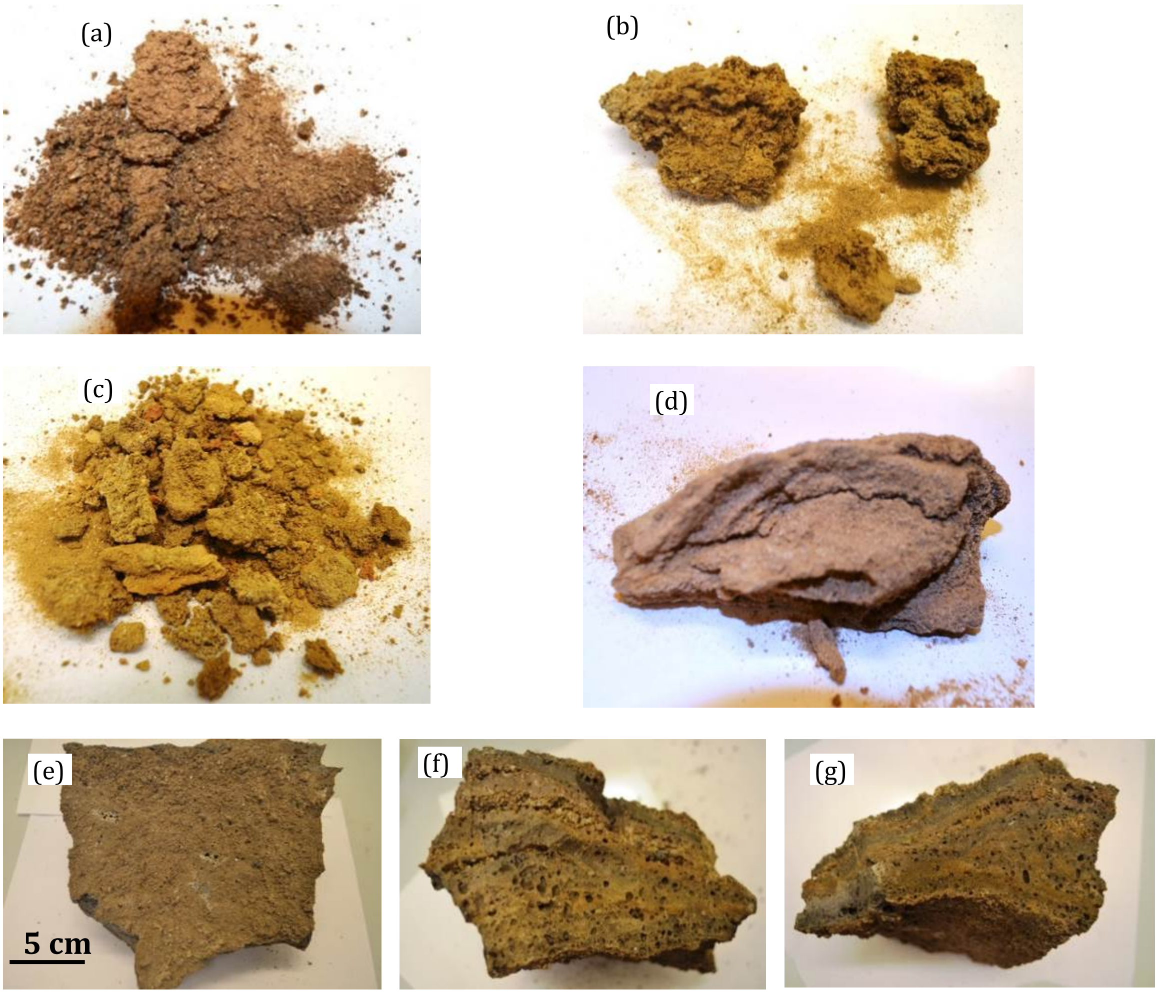


Figure 16. Photos of general view of (a) deposit sample #1, (b) close view of some coarse lumps, (c) general view deposit sample #2, (d) close view of some coarse lumps with layered structure, (e-g) show photos of slag sample from (e) top-down view, (f) left side view, (g) front side view.

The macroscopic appearance and microstructure of the three samples were also evaluated. The results show that, compared to the ash deposit #1 collected from the lower section of the combustion chamber, the ash deposit #2 collected at the top of the combustion chamber contains finer particles and molten phases. The chemical and mineralogical compositions of the three samples were determined by XRF and XRD analysis, respectively. The ash deposit #2 is rich in Ca, S, Cl and alkali metals, while the ash deposit #1 contains mainly non- and less volatile Si, Ca, Al and Fe. Differences in chemical compositions of the two deposit samples are mainly related to different transformations, partitioning and chemical reactions of ash forming elements in the MSW. XRD analyses show that the ash deposit #1 contains mainly akermanite and wollastonite, while the ash deposit #2 is rich in sulphates. SEM-EDX analyses agree well with the XRF and XRD analysis results. The ash deposit #2 is formed due to condensation, agglomeration and sintering of sulphates, which are rich in Ca, S, Cl and alkali metals. Formation of the ash deposit #1 is attributed to accumulation and aggregation of rather large particles containing high temperature materials. Finally, the slag sample collected close to the grate has a dense and layered structure, which is formed due to formation, accumulation and melting of silicates.

Gasification – WP2.2

Conference presentation on S-Cl-Na-K chemistry during MSW gasification: cooperation between Energos and SINTEF-ER

Using Municipal Solid Waste (MSW) as an energy source (aka WtE - Waste-to-Energy or EfW - Energy from Waste), with a significant fraction being of biogenic origin and therewith renewable, is a well-established practice in several EU countries as well as parts of Asia and North America. The most common technological solution is combustion on a moving grate with heat and/or power production. However, according to Eurostat, 37% of EU-27 MSW (i.e. in the order of 90 million tons) are neither material- nor energy-recovered but currently landfilled. As illustrated by the EU Waste Hierarchy, WtE is, combined with material recycling and biological treatment, an efficient and well-regulated waste management alternative, but sometimes suffers from a negative public perception. In this context, innovative thermal solutions, such as MSW gasification may both avoid such pitfalls as well as offer additional advantages.

However, gasification is not exempt from operational challenges with ash-related ones (corrosion, fouling, slagging) being of prime importance. These challenges have an impact on the plant overall performance and hence profitability.

Using Energos technology operational as case study, this work proposes a thermodynamic study on the chemistry of selected ash-forming elements (alkalis, i.e. Sodium Na and Potassium K), Sulphur (S) and Chlorine (Cl) during gasification as they are central in the aforementioned ash-related challenges. Energos technology is a grate-based MSW gasification concept. The principle is a two-stage process where gasification (syngas production) is directly followed by combustion of the syngas to produce heat/power. Several Energos plants are currently in commercial operation or under procurement/construction.

Little attention has been given to alkalis at reducing conditions in thermal systems, except for a few studies. During combustion, various transformations are taking place involving ash compounds and reducing conditions may affect both speciation and phase distribution. **To optimise plant operation and develop gasification models, it is important to understand both the fluid dynamics and thermal processes.** A first beneficial step to better comprehend the latter is the use of thermodynamic equilibrium methods. Thermodynamic equilibrium calculations have proven their relevance in a variety of applications and despite limitations; they provide valuable information on chemical trends. Such calculations are a powerful tool and, at present, represent the most practical computational possibility for investigating elemental chemistry in a multicomponent and multi-phase complex thermal system. **This study presents the Na-K-S-Cl-containing products and chemical trends at varying temperature with focus on the formation of corrosive compounds during MSW gasification.**

This succinct thermodynamic study addresses the waste 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, 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 with temperature: However, stable operating conditions are preferable. Different approaches exist to abate ash-related challenges, but selecting one (or a combination) is complex and should be based on both practical and economic considerations.

Detailed biomass particle thermal degradation model in Eulerian-Lagrangian CFD modelling

Devolatilisation is a crucial step in the processes of thermochemical conversion of solid fuels, in particular, biomass, which typically has a high volatile matter content. Depending on Biot numbers, the thermal behaviour of biomass particles in the devolatilisation process may differ significantly. As a result, thermal degradation of the biomass is determined by whether the particles are thermally thick or thin. Due to the inherent physical properties, it is difficult to prepare small particles of biomass especially for the lignocellulosic biomass. Therefore, the Biot numbers of biomass particles in a high-temperature devolatilisation process may not be sufficiently low to neglect temperature gradients within particles. In order to simulate the thermochemical degradation of thermally thick biomass particles, a sub-model proposed by Ström and Thunman[15] has been implemented in the Eulerian-Lagrangian CFD model developed at NTNU within the OpenFOAM framework (NELLI).[12] The implemented sub-model for thermally thick particles treats a biomass particle with three distinct layers: moist wood, dry wood, and char. Chemical and physical changes can then be modelled accordingly in each layer as a function of time. Figure 17. shows the evolution of two differently sized particles. In the dry wood layer, the devolatilisation is simulated by a primary and a secondary stage. In the primary stage, the biomass decomposes to a mixture of light gases, tar, and char.

,The tar may also decompose to light gases through the secondary decomposition. The neighbouring layers exchange heat and mass. In this manner, the gradients of temperature and species within a particle can be predicted. This is work in progress and will continue in 2016. The performance of the CFD model is examined by a detailed comparison with experimental data from a drop tube reactor,[16] and will be presented at the European Biomass Conference and Exhibition (EUBCE) in June 2016.[17]

Pyrolysis – WP2.3

There was no activities within this topic in CenBio in 2015.

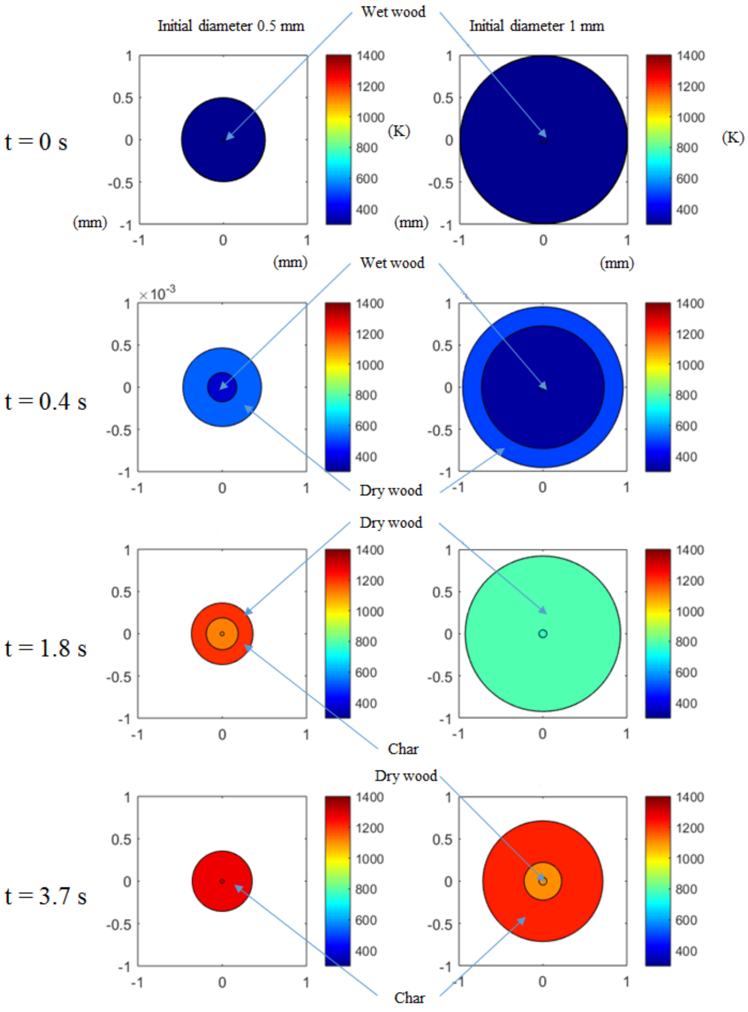


Figure 17. Time evolution and the thermochemical degradation of thermally thick biomass particles of two differently sized particles.

Anaerobic digestion – WP2.4

Microbial population dynamics

The population dynamics of two x 2 parallel biogas reactors at laboratory scale initially operating close to the edge of stability (i.e. overloaded with substrates) were studied for twelve weeks. The reactors were fed with a mixture of whey permeate, fish ensilage and cow manure. Loading rate of whey permeate was further increased in one of each parallel until pH suddenly dropped below six, causing a drop in digester's activity. The rescue action consisted of replacing 30% of digestate with cow manure and effluent (produced digestate) from the previous 10 days. When activity recovered, loading was stepwise increased in all reactors. It turned out that only the reactors subjected to temporary overloading and subsequent rescue achieved the capacity to sustain continuous high loading at 9 g COD L^{-1} day^{-1}. One additional reactor was running as control at 5 g COD L^{-1} day^{-1}.

In order to see if there was any correlation between population dynamics and process performance, approximately 50 bacterial orders were classified and more than 170 bacterial genera were characterised (using Roche Ultra-deep pyrosequencing). **Results indicate that the rescue action had a notable impact on the community composition and that less than 1% relative abundance at genus level may be significant for process performance.**

Concerning methanogen population, the number of sequences assigned to Archaea (see Figure 20) tends to be reduced from week 2 to 11 from about 4% to about 1%. *Methanosarcina* generates methane via acetotrophic pathway which might be the case for most of the samples we studied here; while very notably, in the reactor with the abrupt increasing content of acetic acid, the absolutely dominant methanogen is *Methanocorpusculum* (named "B1 uke 10", see Figure 18) which is consuming mainly hydrogen and carbon dioxide to produce methane.

The results demonstrated the usefulness of studying microbial communities in much more detail by molecular techniques in order to develop robust processes.

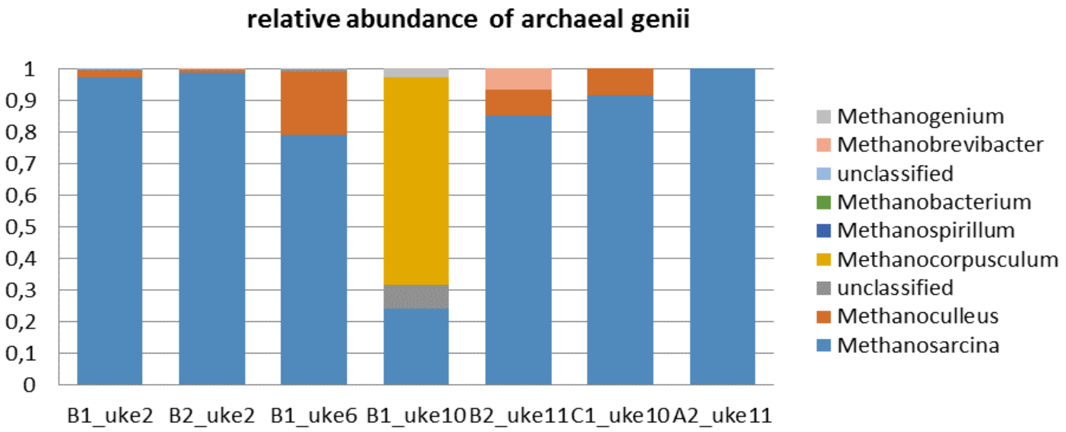


Figure 18. The relative abundance of archaeal genii in the biogas reactors. Note that the reactor named "B1 uke 10" had a very high concentration of acetate at this moment, while the reactor named B2 had been treated by a previous loading shock in week 4 and handled the increasing loading better later on (less acetate accumulation).

Two-phase anaerobic digestion systems

Anaerobic digestion usually takes place in one single reactor where all microbial degradation steps of the substrate to methane is carried out. This means that the acid-forming and methane-forming microorganisms are kept together in a single reactor system. It is a delicate balance between these two groups of organisms, since they differ widely in terms of physiology, nutritional needs, growth kinetics and sensitivity to environmental conditions. Thus, **a physical separation of acid-formers and methane-formers in two separate reactors might lead to a more stable and efficient biogas process.** To investigate this, two-phase biogas systems was set up at the biogas laboratory at Ås campus (see Figure 19).

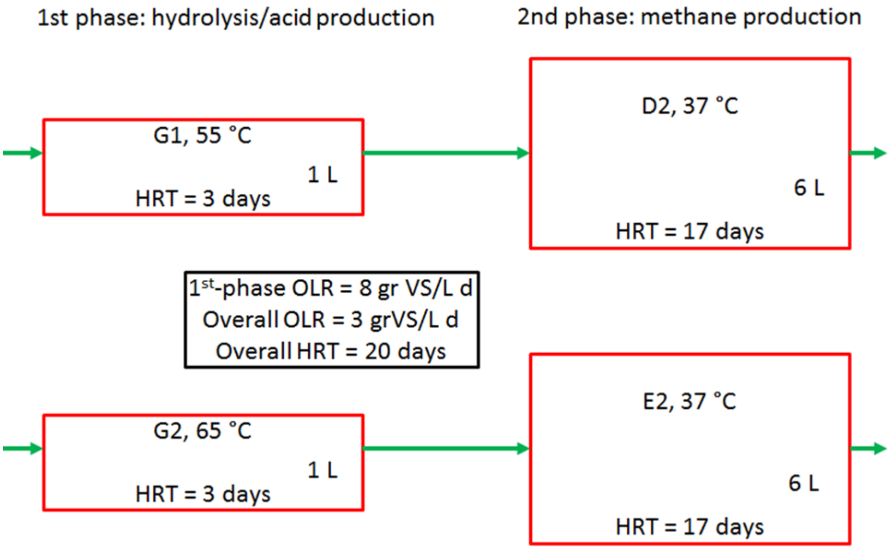


Figure 19. Setup of anaerobic digestion two-phase system. HRT= Hydraulic retention time.

Since hydrolysis and acid production is much faster than methane production, the 1st phase reactor was smaller (1L) than the 2nd phase reactor (6L). With a substrate (food waste) flowrate of 0.35 L/d this meant a hydraulic retention time (HRT) of 3 and 17 days for the 1st and 2nd reactors, respectively. The 1st phase reactor was run at thermophilic temperatures, while the 2nd phase was at mesophilic temperature. Two 2-phase systems were investigated where the only difference were the temperature in the thermophilic reactors (G1 and G2).

The two reactor set ups were run stably for 120 days, and both systems performed very similar. As expected the pH in the phase one reactors (G1, G2) were low (5.6-5.8), while the 2nd phase methane producing reactors (D2, E2) had a relatively high pH (7.9-8.1). The 1st phase reactors had a high soluble COD around 16 g/l, which was efficiently reduced (and converted to biogas) in the 2nd phase to around 1.5 g/L. Overall, both set-ups converted 78 % of the organic material to biogas.

Work is now in progress to characterise the microbial communities in the 4 reactors. It is expected very different and specialised populations in 1st phase and 2nd phase reactors. The 10 °C temperature difference in G1 and G2 did not affect performance of the reactors, but might affect the composition of the microbial communities. Finally, we will compare the performance of 2-phase system with a single-phase system, both about biogas production and microbial community composition.

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 at NTNU was completed, with PhD defense in January 2015. The PhD study "*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 pre-treatment 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*. Energy. **2015**, 88, 443-456.
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. *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.

After defending this thesis, Quang-Vu Bach has been very active, continuing with finalising submitted publications as well as producing several new ones based on experimental results from his PhD work. These are:

- Bach, Quang Vu; Tran, Khanh-Quang; Skreiberg, Øyvind. *Combustion kinetics of wet-torrefied forest residues using the distributed activation energy model (DAEM)*. In press in Applied Energy. **2016**
- Bach, Quang Vu; Tran, Khanh-Quang; Skreiberg, Øyvind. Comparative study on the thermal degradation of dry- and wet-torrefied woods. In press in Applied Energy. **2016**
- Tran, Khanh-Quang; Trinh, Trung Ngoc; Bach, Quang Vu. *Development of a biomass torrefaction process integrated with oxy-fuel combustion.* Bioresource Technology **2016.** vol. 199.
- Bach, Quang Vu; Skreiberg, Øyvind. *Upgrading biomass fuels via wet torrefaction: A review and comparison with dry torrefaction*. Renewable & Sustainable Energy Reviews. **2015** vol. 54.
- Bach, Quang Vu; Tran, Khanh-Quang. *Dry and wet torrefaction of woody biomass – A comparative study on combustion kinetics*. Energy Procedia. **2015** vol. 75.
- Bach, Quang Vu; Tran, Khanh-Quang. *Wet Torrefaction of forest Residues – Combustion Kinetics*. Energy Procedia. **2015** vol. 75.
- Bach, Quang Vu; Tran, Khanh-Quang; Skreiberg, Øyvind. Accelerating wet torrefaction rate and ash removal by carbon dioxide addition. Fuel processing technology. **2015**vol. 140.
- Bach, Quang Vu; Tran, Khanh-Quang; Skreiberg, Øyvind. *Hydrothermal pretreatment of fresh forest residues: Effects of feedstock drying*. Biomass & Bioenergy. **2015** vol. 85.

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 summarised in the STOP handbook, shown inFigure 20, available at the STOP webpage[18], where an updated publications list from the project is available.

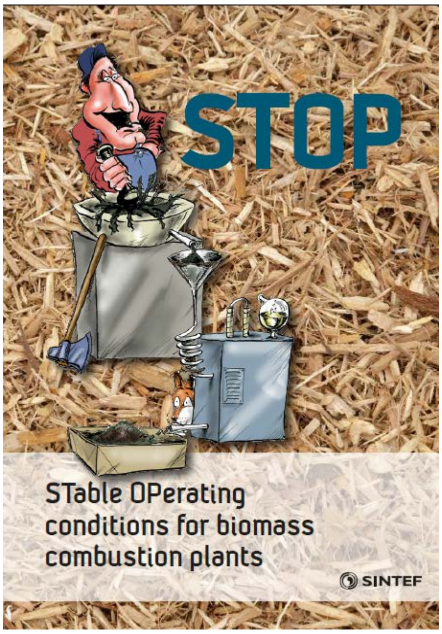
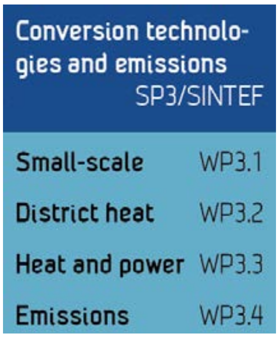


Figure 20.
The STOP handbook.
(Illustration: SINTEF/Kjetil Strand)

Conversion Technologies and Emissions – SP3



Conversion technologies and emissions
SP3/SINTEF

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

WBS of SP3.

Øyvind Skreiberg

Leader of Conversion Technologies and Emissions

SINTEF Energy Research
(Photo: Gry Karin Stimo)

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 NOx, 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, Akershus Energi bioenergy plant at Lillestrøm in 2014 and Statkraft Varme bioenergy plants in Trondheim and Kungsbacka in Sweden in 2015);
- CFD modeling;
- Experimental studies;
- Literature surveys (e.g., NOx 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 utilising 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 minimised, 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.

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

Through CenBio, SINTEF Energy Research has in recent years actively contributed to the European standardisation work, CEN/TC 295 working groups 5, 6 and 7.

CEN (Central European Norms) is a private, international, non-profit organisation based in Brussels and is one of three European standardisation organisations officially recognised by the EC and EFTA as being responsible for developing and defining voluntary standards at European level. The standardisation activities of CEN are steered by the Technical Board (BT). Technical Committees (TCs) prepare standards. Working Groups (WGs) develop the standards (e.g. CEN/TC 295 WGx). Experts, appointed by the CEN Members but speaking in a personal capacity, come together and develop a draft that will become the future standard. CEN started to develop standards for residential solid fuel-burning appliances in 1992 through CEN/TC 295. In 1999, CEN/TC 295 approved the first European product standards on most commonly used residential solid fuel-fired appliances. Since 2002, all CEN member countries have withdrawn their existing national standards giving requirements for construction, safety, heat output, efficiency and emissions. In 2000 TC 295 started new work to modify these four product standards into harmonised standards (EN) according to the rules of the EU Directive for Construction Products.

Regarding the wood stove test standard (Residential solid fuel burning appliances), a plurality of national standards, test methods and labels have emerged to compensate for the currently outdated standard. Meaning costly, confusing and time-consuming approval processes for the manufacturers. Some of the main reasons for harmonising the current plurality of standards are:

- There is no harmonised particle measuring method for fireplaces and wood stoves in Europe
- Standards (EN13240, EN13229) for wood burning fireplace insets and wood stoves set requirements mainly on safety, efficiency and CO emission
- Outdated (1999) standards for wood burning appliances
- Particle emissions from wood heating is regarded as a significant source of hazardous emissions
- Beside countries applying the EN 13240 including DIN+ (VDI 2066) for dust measurements, a few European countries such as Norway and the United Kingdom have their own standards for measuring particles and also other countries (Austria, Germany, Denmark) set emission limits for PM from wood firing
- Different traditions in Europe how to measure particles makes it difficult to find a compromise for one measuring method (8+15 years and counting as of today)
- Norway and the United Kingdom use a dilution tunnel to measure solid + condensed particles all over the combustion cycle at different burn rates (both good and poor combustion conditions were tested)
- Germany's most frequently used method VDI 2066 measures in the chimney with a heated filter for 15/30 min at nominal heat output

Through this work a series of documents have been prepared, the FprEN 16510-series, by Technical Committee CEN/TC 295 “Residential solid fuel burning appliances”, the secretariat of which is held by BSI. The documents have been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association. As of February 2016, the proposed 16510-series of documents has been submitted for a formal vote. Together the FprEN 16510-2-1, FprEN 16510-2-2, FprEN 16510-2-3 and FprEN 16510-2-4 the series will totally supersede EN 13240:2001, EN 13229:2001, EN 12815:2001, EN 12809:2001. The revision of these European Standards takes into account the comments received at their 5-year review. The structure of EN 16510, Residential solid fuel burning appliances, is as follows:

— Part 1-0: General requirements and test methods;

— Part 2-1: Roomheaters;

— Part 2-2: Inset appliances including open fires;

— Part 2-3: Cookers;

— Part 2-4: Independent boilers — Nominal heat output up to 50 kW;

— Part 2-5: Slow heat release appliances;

— Part 2-6: Appliances fired by wood pellets.

Concerning the measurement method, the current documents now include two methods of choice when it comes to measure the total amount of suspended particles - one method much like the current DIN+ method and one method similar to, although much changed, the current Norwegian dilution tunnel test method NS 3058-59. Annex F in part 1 contains two methods to measure particulate matter. The first method is measurement by sampling a partial flue gas sample from the measurement section over a heated filter. The heated filter samples the solid fraction of the total particulate matter concentration. The second method measures particles by sampling a partial flue gas sample from a full flow dilution tunnel using a filter at ambient temperature.

The following comments all the main objections from the Norwegian experts, to the full flow dilution tunnel method currently implemented in FprEN 16510-1: 2013 Residential solid fuel burning appliance general requirements and test methods:

Number	Issue	Comment
1	**Test fuel**	To avoid misuse of a stove, the combustion chamber should be restricted by physical obstacles to avoid unintentional overloading by the end-user, independent of the manufacturers declaration of a specific amount of test fuel. Alternatively, the amount of test fuel should be calculated according to the combustion chamber size similar to the safety test.
2	**Low heat output testing**	If a manufacturer do not declare low heat output, the stove should be physically restricted such as not to allow down-throttling to more than e.g. 10% of the nominal effect.
3	**Filter sampling starts 3 min after ignition**	The most crucial part of the test period is excluded and will give too low measurements results of the emissions.
4	**Filter temperature**	A temperature variation between 70 °C to 160 °C will result in varying results and will make marked surveillance challenging. A stricter range should be chosen.
5	**Filter type**	The dilution tunnel method should use the same filters types as heated filter method, which is of the quartz fibre filter type.

The inclusion of the second method is much thanks to the active participation from SINTEF Energy Research, SP Fire Research AS, Standard Norway and the Norwegian Environment Agency, in the compilation of these standardization documents. The work of assuring that a sufficiently acceptable test method is implemented will continue at SINTEF, at least in 2016, depending on available budgets. Related to this work is also the harmonization of FprEN 16510 with the current Eco-design requirements, as there is currently a mismatch between the requirements in Eco-design and the test methods described in FprEN 16510. The three methods referred to in Eco-design are the current valid standards in Europe; NS 3058-59, EN13240 DIN+ and the English method, while the two methods described in FprEN 16510 are some altered versions of the German and the Norwegian test method.

Eco-design

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 Eco-design 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 Eco-design requirements for energy efficiency and for emissions of particulate matter (PM), organic gaseous compounds (OGC), CO and nitrogen oxides (NO_x). The Eco-design 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. 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 Eco-design requirements.

KPN WoodCFD - new in-kind project in CenBio

KPN WoodCFD is the successor to KPN StableWood, a CenBio in-kind project that was finalised in 2014, focusing on clean and efficient wood stoves through improved batch combustion models and modelling approaches, specifically:

- Model development: improved transient wood log and gas release models, transient heat transfer and storage models, reduced kinetics models (NOx and soot), and transient models and approaches for heat distribution in the building; and verification of these.
- Simulations: transient and stationary CFD simulations of wood stoves, and room and building integration simulations; and verification of these.

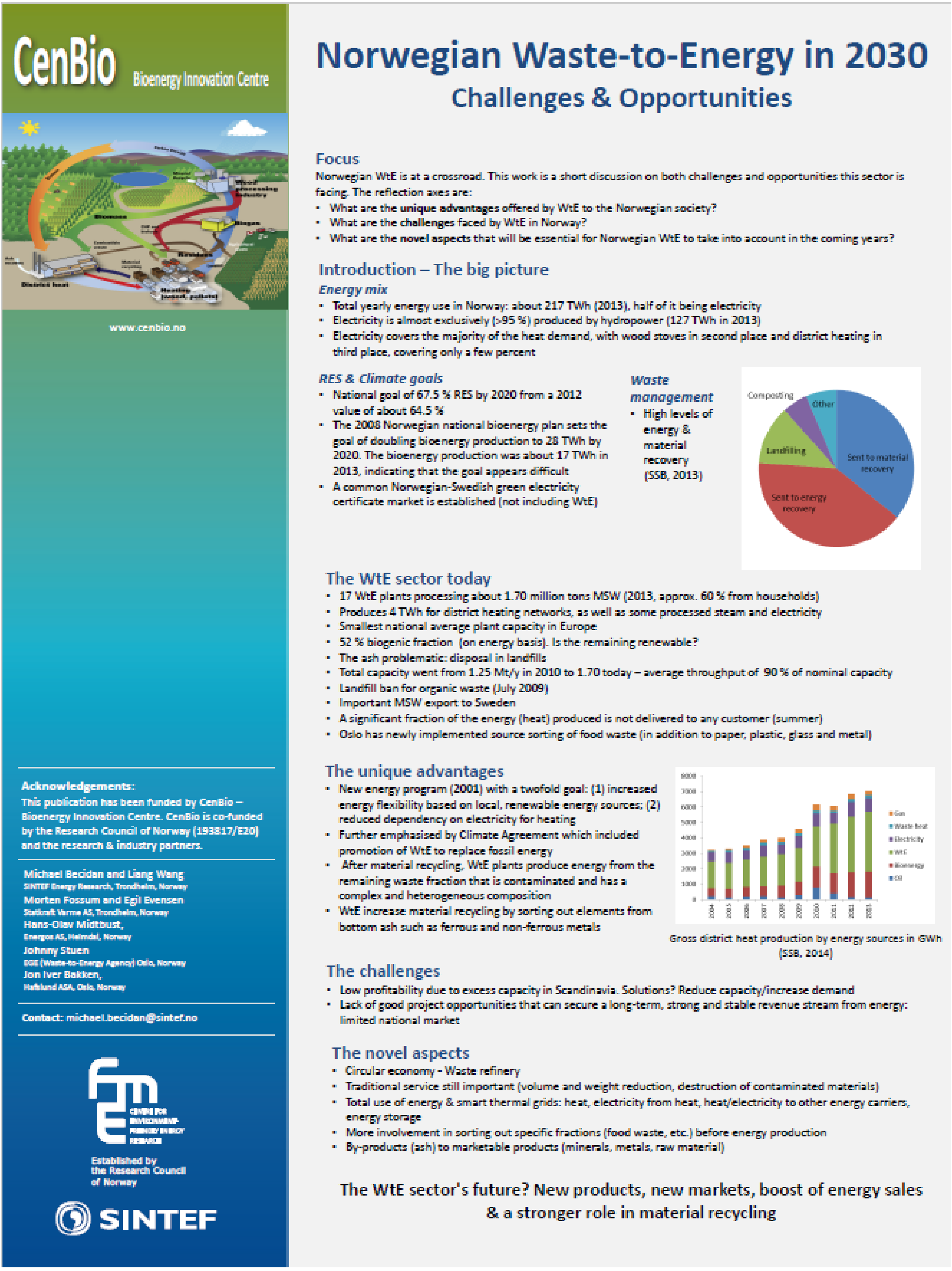
The project started January 2015 and will last until December 2018, and involves the same partners as in StableWood. See the WoodCFD webpage for more information.[19]

District heat – WP3.2

This work package focuses on Waste-to-Energy (WtE) challenges. In 2015, the activity was related to discussions on the future of Norwegian WtE and a workshop on bioenergy, as well as participation in international networks, such as the IEA Bioenergy Task 36[20] (*Integrating Energy Recovery Into Solid Waste Management Systems*).

"Norwegian WtE 2030": ICheaP12 conference article

SINTEF-ER, Statkraft, Hafslund, EGE Oslo and Energos co-authored a peer-review conference article and a poster presentation addressing the opportunities and challenges in Norwegian WtE. A difficult but necessary exercise is to secure the place of the sector in an ever-changing market and regulatory environment: see key points in the conference poster reproduced below.



CenBio Bioenergy Innovation Centre

www.cenbio.no

Norwegian Waste-to-Energy in 2030

Challenges & Opportunities

Focus

Norwegian WtE is at a crossroad. This work is a short discussion on both challenges and opportunities this sector is facing. The reflection axes are:

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

Introduction – The big picture

Energy mix

- Total yearly energy use in Norway: about 217 TWh (2013), half of it being electricity
- Electricity is almost exclusively (>95 %) produced by hydropower (127 TWh in 2013)
- Electricity covers the majority of the heat demand, with wood stoves in second place and district heating in third place, covering only a few percent

RES & Climate goals

- National goal of 67.5 % RES by 2020 from a 2012 value of about 64.5 %
- The 2008 Norwegian national bioenergy plan sets the goal of doubling bioenergy production to 28 TWh by 2020. The bioenergy production was about 17 TWh in 2013, indicating that the goal appears difficult
- A common Norwegian-Swedish green electricity certificate market is established (not including WtE)

Waste management

- High levels of energy & material recovery (SSB, 2013)

The WtE sector today

- 17 WtE plants processing about 1.70 million tons MSW (2013, approx. 60 % from households)
- Produces 4 TWh for district heating networks, as well as some processed steam and electricity
- Smallest national average plant capacity in Europe
- 52 % biogenic fraction (on energy basis). Is the remaining renewable?
- The ash problematic: disposal in landfills
- Total capacity went from 1.25 Mt/y in 2010 to 1.70 today – average throughput of 90 % of nominal capacity
- Landfill ban for organic waste (July 2009)
- Important MSW export to Sweden
- A significant fraction of the energy (heat) produced is not delivered to any customer (summer)
- Oslo has newly implemented source sorting of food waste (in addition to paper, plastic, glass and metal)

The unique advantages

- New energy program (2001) with a twofold goal: (1) increased energy flexibility based on local, renewable energy sources; (2) reduced dependency on electricity for heating
- Further emphasised by Climate Agreement which included promotion of WtE to replace fossil energy
- After material recycling, WtE plants produce energy from the remaining waste fraction that is contaminated and has a complex and heterogeneous composition
- WtE increase material recycling by sorting out elements from bottom ash such as ferrous and non-ferrous metals

Gross district heat production by energy sources in GWh (SSB, 2014)

The challenges

- Low profitability due to excess capacity in Scandinavia. Solutions? Reduce capacity/increase demand
- Lack of good project opportunities that can secure a long-term, strong and stable revenue stream from energy: limited national market

The novel aspects

- Circular economy - Waste refinery
- Traditional service still important (volume and weight reduction, destruction of contaminated materials)
- Total use of energy & smart thermal grids: heat, electricity from heat, heat/electricity to other energy carriers, energy storage
- More involvement in sorting out specific fractions (food waste, etc.) before energy production
- By-products (ash) to marketable products (minerals, metals, raw material)

The WtE sector's future? New products, new markets, boost of energy sales & a stronger role in material recycling

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SINTEF

Clinical waste – Is co-combustion in WtE plants feasible?

There is an increasing interest for the disposal and energy recovery of "new/unusual" waste fractions, especially hazardous ones, in MSW incinerators. This opens the opportunity for a win-win situation: local and responsible treatment of non-material recyclable waste fractions and additional economic revenue for WtE actors. What about healthcare-related waste fractions?

Several important points relevant for (combustion and/or) co-combustion of clinical wastes from health care institutions can be inferred from the information gathered in D3.2.16:

- **Combustion behaviour**: a very heterogeneous material & some problematic elements

Wastes from health care institutions are clearly a very heterogeneous waste fraction. While some fractions have high-energy content (plastics), others will have high moisture contents (materials contaminated by organic matter).

Some fractions contain high amounts/concentrations of potentially harmful substances and/or chemical elements such as PVC that contains more than 50 wt% Cl, a chemical element involved in corrosion. However, MSW is also heterogeneous so this aspect may not be a main challenge for large MSW incinerators, especially as the amounts of this specific waste fraction is small. The wastes can be mixed and/or shredded to improve homogeneity but it may not be possible to do this together with MSW as the Waste Incineration Directive (WID) article 6.7 states that *Infectious clinical waste should be placed straight in the furnace, without first being mixed with other categories of waste and without direct handling*.

It is similarly specified in Avfallsforskriften for infectious waste (§ 10-12. *Smittefarlig avfall): Ved forbrenningsanlegg som har tillatelse til å behandle smittefarlig avfall, skal dette føres direkte inn i forbrenningsovnen uten at det blandes med andre avfallstyper først og uten direkte berøring.*

- **Logistics**: transport, handling and storage may pose specific requirements

In order to reduce the specific risks associated with these wastes, for HSE and/or regulatory reasons imposed by the authorities, some specific measures may have to be implemented to ensure proper and safe handling of health care wastes from their collection sites to their introduction into the combustion chamber. Typical measures include: dedicated containers for storage and transport, possibility for disinfection, dedicated loading system or direct introduction in the feed hopper, segregated storage and transfer areas, eventually with refrigeration.

- **Technological considerations**: thermal treatment technology – is there a preferred solution?

For dedicated installations burning hazardous/infectious wastes, rotary kilns have often been a preferred technology as they are very robust and reach high operating temperatures that can destroy most harmful substances.

When it comes to co-processing clinical wastes in MSW incinerators, the situation is different as about 90% of MSW incinerators in the world are grate incinerators. Modern grate incinerators can handle solid fuels with large particle sizes and high moisture contents, a main limitation being the range of LHV (Lower Heating Value) accepted. As wastes from health care institutions often represent small volumes compared to MSW, and as long as they are incinerated on the grate with a large fraction of MSW, it is little probable that overall operation (combustion process and flue gas cleaning especially) will be significantly disturbed or that the eventual disturbances cannot be handled by the operators (after a period of adaptation). However, concerning operation, WID article 6.2 indicates that (bold added)

Co-incineration plants shall be designed, equipped, built and operated in such a way that the gas resulting from the co-incineration of waste is raised in a controlled and homogeneous fashion and even under the most unfavourable conditions, to a temperature of 850 °C for two seconds. ***If hazardous wastes with a content of more than 1 % of halogenated organic substances, expressed as chlorine, are co-incinerated, the temperature has to be raised to 1 100 °C.***

Avfallsforskriften (Vedlegg IX) poses the same requirement for hazardous and infectious waste:

For forbrenningsanlegg som forbrenner farlig avfall og/eller smittefarlig avfall som inneholder mer enn 1% halogenerte organiske forbindelser, uttrykt som klor (Cl), skal temperaturen økes til minst 1100 °C i minst 2 sekunder.

This point infers that if infectious/hazardous wastes from health care have a high content of halogenated organic substances (halogens are F, Cl, Br and I), the minimum operating temperature has to be greatly increased. This is very detrimental to existing plants and such a case would probably mean that co-incineration with MSW is not to be considered as a viable option.

Co-incineration of wastes from health care institutions with MSW appears to be a win-win opportunity both for the waste producer (disposal of the waste by a professional actor) and the WtE sector (extra revenues). Operational challenges (combustion process) do not seem unsurmountable as long as the operating temperature does not have to be altered. However, the current regulation imposes stricter requirements on several aspects of the waste management value chain (transport, handling, storage, feeding) and all these measures will cost money if they are not eased or alleviated by the responsible authorities.

Workshop *How to ensure bioenergy production in a sustainable and efficient manner in Norway? – From strategies to actions*

CenBio partners appreciate workshops in order to get a quick overview on a specific topic, meet relevant actors and exchange ideas. In 2015, the following workshop was organised by SINTEF-ER:

How to ensure bioenergy production in a sustainable and efficient manner in Norway? – From strategies to actions

Both R&D representatives and industry (both CenBio and non-CenBio) were invited in order to cover the entire value chain.

The day began with a short introduction to how CenBio works with sustainability assessment of the various value chains. This was followed by two interesting and educational presentations from researchers in our neighbouring country, Sweden. We heard what the Swedish forestry sector looks like, what are their challenges and which opportunities they investigate and implement in order to get a more efficient forestry industry ("Efficient forest fuel supply system" / "Storage"). Then we followed a presentation from Arbaflame, a company that produces upgraded biofuels by steam explosion for use as coal substitute through cofiring in coal fired plants.

The first part of the afternoon was devoted to Norwegian district heating and we heard interesting presentations from Hafslund, Telemark University College and Statkraft. They all presented district heating from their respective angle, including new technologies, opportunities and challenges. Waste-to-Energy, biomass combustion and biogas production were covered during this part of the workshop. The presentations gave a good insight into this part of bioenergy production that is the biggest in Norway when it comes to bioenergy production apart from residential heating (wood stoves). Finally, an interesting report from the Norwegian Environment Agency (Miljødirektoratet) was presented. This report presents concrete measures that can be implemented to reach a low-carbon society in the coming decades. It will be a central support/tool for politicians in their decision-taking processes including policy shaping.

The day ended with a good discussion about politics, profitability and obstacles. During the discussions it became clear that there are some political issues (clear strategy, regulatory/legal framework) which represent great obstacles. As there were no politicians present the attendants discussed shortly how it could be possible to inform decision makers and cooperate with politicians.

Agenda and participants list was as follows:

22 September 2015

Park Inn Oslo Airport Hotel, Gardermoen

09:30		**Welcome and safety**: Judit Sandquist, SINTEF ER
09:40		**Sustainability and efficiency in bioenergy production:** Carine Lausselet, NTNU
10:00		**Sustainability and efficiency in biomass logistics**
	10:00	Efficient forest fuel supply system – Maria Iwarson-Wide, Skogforsk, Sweden
	10:30	Storage – Erik Anerud, Swedish University of Agricultural Sciences
	11:00	Biomass upgrading – Rune Brusletto, Arbaflame
11:30		*Lunch*
12:30		**Sustainability and efficiency in conversion technologies and end-use**
	12:30	District heating in Statkraft– Torbjørn Mehli, Statkraft
	13:00	Biogas production – Rune Bakke, Høyskole i Telemark
	13:30	District heating system in Oslo county – Cato Kjølstad, Hafslund
14:00		***Sustainability and efficiency from a governmental angle***
	14:00	The role of bioenergy in a low-carbon society – Kristin Madsen Klokkeide, Norwegian Environment Agency
14:30		*Tea/coffee break*
15:00		**Workshop**
	15:00	Plenum discussions chaired by Judit Sandquist
	16:00	Conclusions from today's workshop
16:15		**Closure**

Last name	First name	Organization
Anerud	Erik	SLU
Bakke	Rune	Telemark University College
Becidan	Michael	SINTEF Energi
Brusletto	Rune	Arbaflame
Due	Eilif	Norges Skogeierforbund
Fronth Nyhus	Pa	BITNG project
Gjølsjø	Simen	NIBIO
Govasmark	Espen	EGE Romerike biogassanlegg
Granli	Karine	Energigården AS - Senter for bioenergi
Houshfar	Ehsan	Energos AS
Iwarsson Wide	Mia	Skogforsk
Jacobsen	Gerd	SINTEF Energi
Kjølstad	Cato	Hafslund Varme AS
Klokkeide	Kristin Madsen	Miljødirektoratet
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Melbye	Anne Marit	Rambøll Energi
Qvenild	Marte	SINTEF Energi
Rørstad	Per Kristian	INA, NMBU
Sandquist	Judit	SINTEF Energi
Skjelhaugen	Odd Jarle	NMBU
Skreiberg	Øyvind	SINTEF Energi
Stuen	Johnny	Energigjenvinningsetaten, Oslo Kommune
Talbot	Bruce	NIBIO

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 utilisation 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 optimisation. In 2012, a pop-tech. article on the status of biomass CHP in Norway, and the way forward, was published in Xergi[21]. The list below shows the main ideas of the article:

- 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.

Energy storage and low-temperature heat utilization for heat and power production

District heating consumption in Norway has increased during the last 10 years as shown in Figure 24. From 2012 to 2013, the increase was 11.3 % partly due to the start-up of new district heating and cooling plants and the expansion of existing plants. During the entire period service industries have accounted for the largest share of the consumption, and in 2013 their use of district heating accounted for about 3 TWh (65%). The average price for district heating rose from 56.6 øre/kWh in 2012 to 59.2 øre/kWh in 2013. For households and the service sector, the average price was 59.8 and 61.5 øre/kWh respectively, while it was lower for the industry, with 31.4 øre/kWh [1].

Waste-to-Energy (WtE) is a contributor to renewable energy production all over Western Europe with about 400 plants. In Norway, waste incineration is the main energy source for district heating accounting for 43% with 2.3 TWh produced in 2013 (Figure 21). The second largest contributor to district heating is wood chips combustion (1.1 TWh).

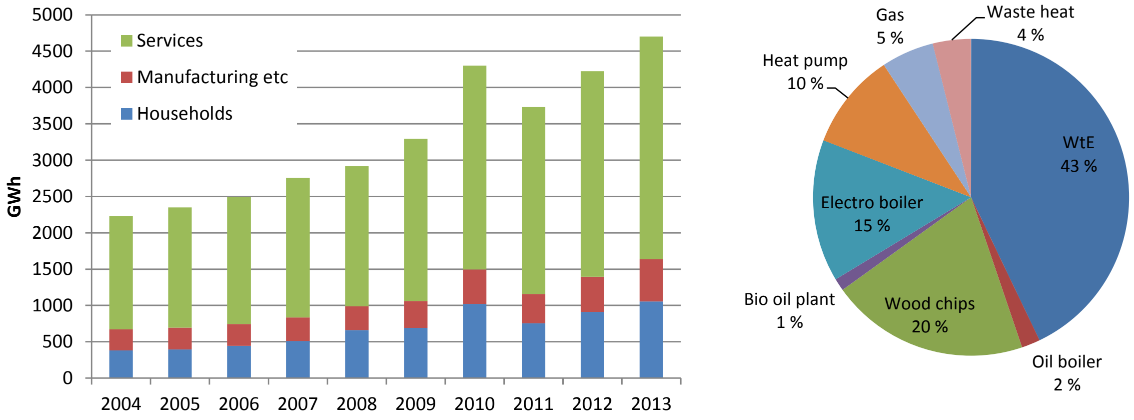


Figure 21. Consumption of district heat by consumer group (left), net production of district heat in Norway in 2013 by type of heat central (right).

WtE is the major contributor in the district heating plants in the largest cities in Norway and constitutes the base load. The supply of waste is quite constant during the year, while the heat demand varies significantly during the year. The result is a need for peak load from other heat sources during the winter season while there are significant amounts of excess heat during the summer. Options for utilizing this surplus heat produced during the summer season are requested. In this work a report has been written in close collaboration with Statkraft Varme and EGE Oslo, which gives an overview of some existing possibilities for utilising the surplus heat either through storage until the winter season or for production of electricity.

ChlorOut

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. 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. 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 NOx and CO.

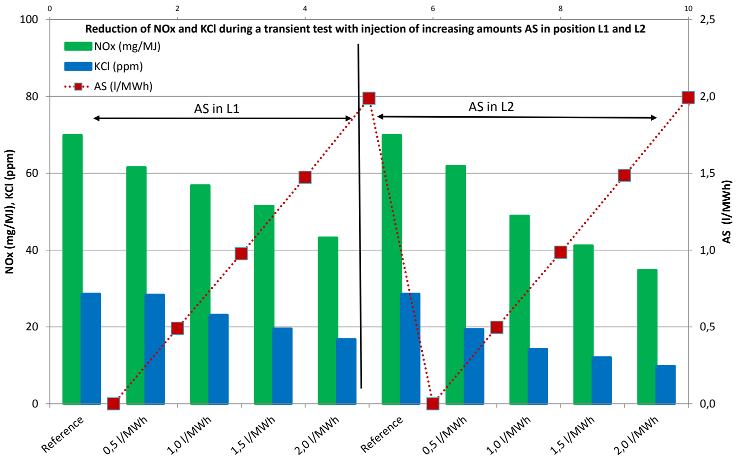


Figure 22: Reduction of NOx and KCl during a transient test with injection of ammonium sulphate in two different positions. AS = Ammonium sulphae (additive). (Vattenfall)

The major achievements from 2010 until February 2016 are summarised here. A permanent injection system for the ChlorOut concept has been installed and fully implemented in regular operation of the boiler. Measurement campaigns were carried out by VRD prior to the permanent installation to optimise the dosage of AS, and measurements with deposit probes revealed that addition of AS reduced the content of KCl in the flue gases and Cl in the deposits. These results supported the implementation of the ChlorOut concept as a strategy to reduce the corrosion rate of the superheaters in the boiler. The permanent installation has been further evaluated 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 was presented in a conference paper at the 22nd FBC Conference[22] in Åbo in June 2015. The paper was honoured with *The Best Paper Award* at the conference. A measurement campaign was performed in the BFB boiler in Jordbro based on these experiences. Here the focus was on the flue gas chemistry involving NO and KCl during injection of AS at different operating conditions. Figure 22 shows the importance of position for the simultaneous reduction of NOx and KCl and the performance of AS was better in position L2 at these specific operating conditions.

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 NOx formation and reduction,
- Define state-of-the-art for NOx 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 23) 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.

A similar measurement campaign was carried out at the Akershus Energi BtE-plant in spring 2014. Extensive emission measurements such as those have hardly been carried out earlier at Norwegian BtE plants.

Figure 23:
FTIR gas sampling and conditioning unit.
(Photo: Sascha Njaa, SINTEF)

In 2015 two mapping campaigns have been carried out, one at the Statkraft Varme Marienborg bioenergy plant in Trondheim and another one at the Statkraft Varme bioenergy plant in Kungsbacka in Sweden. The main aim of the former was providing experimental data as input to and as validation for CFD modelling of the plant. This activity has been carried out in WP2.1 and is reported there. The main aim of the latter was operation optimization for emission minimization, providing guidelines and proposals for a real plant. This work resulted in strategies for reduced CO and NOx emissions, strategies that could be implemented at other comparable bioenergy plants.

The intention of the mapping is to 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 modelling

Tools and methods to study emissions from biomass and waste conversion units will be developed. CFD modelling will be an essential part of this work, and combined with detailed chemical kinetics for the gas phase reactions, which is a necessity when modelling fuel NOx 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 NOx 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 NOx emissions and NOx reduction potential from biomass conversion.

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

In the paper we studied NOx 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 24, using biomass as fuel. In biomass combustion applications, the most significant route for NOx formation is the fuel NOx mechanism. The formation of fuel NOx is very complex and sensitive to fuel composition and combustion conditions. Hence, accurate predictions of fuel NOx 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 NOx reduction at a primary excess air ratio of 0.8, comparable to the NOx emission reduction level achieved in the corresponding experiment, demonstrating both the validity of the model and the potential of NOx reduction by staged air combustion.

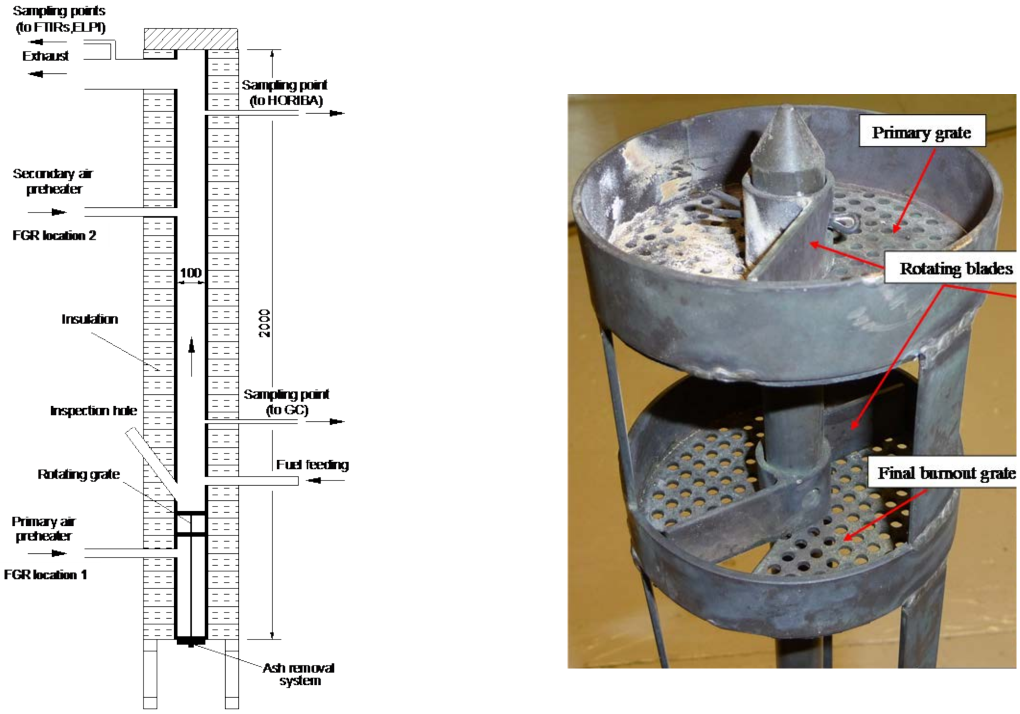


Figure 24: The multi-fuel reactor and the two-level grate system.

The next step could be a further development in order to study mixing behaviour, 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).

In 2015, the focus has been on CFD modelling of the Statkraft Varme Marienborg bioenergy plant in Trondheim, see WP2.1.

Sustainability Analysis – SP4

Birger Solberg

Leader of Sustainability Analysis

NMBU - Norwegian University of Life Sciences
(Photo: Håkon Sparre)

Figure 25: WBS of SP4.

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 2015, the following one from WP4.2 should be mentioned:

Effects of stem-only and whole-tree harvesting on ground vegetation plant species diversity and their cover were investigated as outlined in the below section for WP4.2. An overall loss of ground vegetation biodiversity was induced by harvesting and there was a shift in cover of dominant species, with negative effects for bryophytes and dwarf shrubs and an increase of graminoid cover. Differences between the two harvesting methods at both sites were mainly due to the residue piles and the physical damage made during the harvesting of residues in these piles.

Extended Life Cycle Assessment – WP4.1

During 2015, research activities mainly focused on improving the life-cycle assessment approach to embed the complex temporal and spatial dynamics of the climate impacts from bioenergy systems. The work specifically addressed the changes in biogeochemical (i.e., related to carbon) and biogeophysical (i.e., related to albedo) effects.

Climate impact perturbations from forest bioenergy are temporary, as opposite to warming from fossil carbon that causes a sustained and irreversible temperature increase. Further, cooling contributions from changes in surface albedo can offset the temporary warming from bioenergy and cause a nearly neutral climate change impact. With recent research we associated the impacts from CO_2 emissions from bioenergy to those of short-lived Green House Gases (GHGs). Further efforts also focused on the acquisition of empirical data via satellite retrievals and national forest inventories to derive spatially explicit indicators that can better represent the spatial variability of the impacts.

Participation to prestigious international events and collaborations with leading institutions at an international level were at the core of the activities. The work achieved in CenBio was presented at the UNFCCC conference in Paris “Our Common Future Under Climate Change” (7-10 July). This conference is the scientific events preceding the negotiations of COP21 held in December that provided the scientific basis for the discussion. NTNU is also chairing the global warming task force of the UNEP-SETAC life-cycle initiative and is a member of IEA Bioenergy Task 38.

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. Figure 26 shows changes in ground vegetation with time at a harvesting site. Forest biomass harvesting cannot be considered sustainable if it leads to a loss of biodiversity. We therefore need to understand how biodiversity is affected by intensified forest harvesting, including harvesting of branches and tops. [23]

Figure 26. Changes in ground vegetation with time at Gaupen, Hedmark. Harvesting took place in March 2009 and removal of residue piles in September 2009. (Photos: Ingvald Røsberg.)

Effects of stem-only and whole-tree harvesting on ground vegetation plant species diversity and their cover were investigated at two Norway spruce sites in southern Norway, a steeper and wetter site in western Norway and a less steep and drier site in eastern Norway. In the whole-tree treatment, residue piles were left on-site for six-eight months before removal. We compared the number of plant species in different groups and their cover sums before and shortly after harvesting, and between the different treatments, using non-parametric statistical tests.

An overall loss of ground vegetation biodiversity was induced by harvesting and there was a shift in cover of dominant species, with negative effects for bryophytes and dwarf shrubs and an increase of graminoid cover. Differences between the two harvesting methods at both sites were mainly due to the residue piles and the physical damage made during the harvesting of residues in these piles. The presence of the residue piles had a clear negative impact on both species numbers and cover. Pile residue harvesting on unfrozen and snow-free soil caused more damage to the forest floor in the steep terrain at the western site compared to the eastern site. Although short-term effects on biodiversity were negative, it remains to be seen whether there will be any long-term effect. To this end, studies of changes with time in the ground vegetation at these sites are continuing.

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

In the report "Best scenarios for the forest and energy sectors – implications for the biomass market"[24], the future demand and supply of biomass for bioenergy were assessed in three alternative scenarios, which were specified by different assumptions on economic, technological, climatic and regulatory aspects. Two large scale techno-economic regional global models were soft-linked to each other and used to quantify the impacts of the scenario assumptions: the TIMES-VTT model of global energy systems and the EFI-GTM model of the global forest sector (i.e. forestry, forest industries and wood-based energy). Focus of the scenarios was the period up to 2030, but less comprehensive indicative results were provided up to 2050 as well. While all types of biomass were analysed, developments concerning forest biomass were discussed in more detail.

What all three scenarios have in common is that the use of biomass for energy is projected to increase considerably in the future. The main driver for this development is the decreased competitiveness of fossil fuels either due to their high prices as such or due to their high use costs caused by tightening climate policies. In particular, there is a need to take in use quickly applicable solutions for shifting the transport sector from using fossil fuels to renewable energy. In the regions where the use of solar and wind power were assumed to become increasingly important for power supply, biomass provides options for power system reserves and regulating power. In the long run, the analyses show that bioenergy may provide possibilities even to achieve negative emissions through bio-CCS –technologies (BECCS). Such option appeared important because in some sectors, like in agriculture, emissions can be hard to cut down.

At the global and European level, majority of the energy biomass was projected to come from the agricultural sector. Despite that, the amount of forest chips and roundwood used to produce heat, power and liquid biofuels increased drastically. In order to satisfy this demand for energy wood in a sustainable manner, the analysis show that it is essential that planted area of fast growing forests increases much and that a shift from household fuelwood burning to modern energy technologies takes place to a large extent.

At present, most of the global bioenergy is consumed in traditional small scale uses. In the future, the analysis shows that this picture is expected to change radically. According to the energy systems analysis documented in the report, the total bioenergy use could double to over 100 EJ during 2010–2030. About one third of that amount could be utilised for power and heat production in the energy sector and industry.

When going beyond 2030, the analysis indicates that global bioenergy demand could again nearly double between 2030 and 2050, reaching up to 180 EJ in the two scenarios where the warming of climate is limited to 2 °C through global efforts. Then about 90% of the estimated sustainable global biomass potential would be taken into use, and more than half of the total increase would be used for producing liquid biofuels, mainly for the transport sector. The largest contribution to the increase in bioenergy use would come from energy crops, most clearly when moving beyond 2030. Even though modern energy wood does not play a major role in the total energy biomass palette, its use increases so much that it is essential to have additional supply sources for wood. The development calls for increases in the forest plantation area and large-scale shift from traditional fuelwood use to modern bioenergy.

Sustainable bioenergy can be one of the cornerstones of renewable energy supply when moving to a low carbon society. Nonetheless, the analysis clearly shows that due to the limits on sustainable bioenergy production, a wider portfolio of renewable energy sources and technologies will be necessary for reaching the policy targets to tackle the climate change. Furthermore, considering the high demand for energy biomass projected in the scenarios, it is essential that technical improvements and innovations take place in all areas to relieve the pressure on the resources, let it be energy production and storage, use of energy, or use and reuse of biomass, materials and land.

Numerous uncertainties prevail behind the scenario projections. As mentioned above, the sustainability criteria of biomass will need to be developed further, and once that happened, the new criteria may affect the question to which extent different biomass grades will be considered to be carbon neutral and thus applicable to reduce greenhouse gas emissions in the future. If the palette of biomass sources usable for achieving emission reduction targets is narrowed, the use of other, more costly, carbon neutral energy forms would need to be increased. Future LULUCF (i.e. land use, land use change and forestry) policies are partly tied to that issue. For instance, if changes in carbon stored in forest land would be fully accounted as a part of the annual CO_2 emissions of the countries that might bring changes to forest policies and decrease both the roundwood supply and wood use in the countries affected.

Regarding agro-biomass, the question of the population development, development of the dietary habits and technological change in agriculture are decisive in determining the availability of land for energy biomass supply. Another important and uncertain issue is the impact of climate change on the future harvest levels.

Political choices both in individual countries and internationally are of great importance in shaping the future global use of energy. In two of the scenarios analysed, it was assumed that the climatic warming is limited to 2 ^{o}C. This calls for strong commitment of the countries toward achieving this goal to be taken soon. If this will not happen, as it was assumed in the third scenario, less biomass will be used for energy globally. Still, the decisions already made in the EU create raising markets for bioenergy technology.

In the forest sector, the analyses show that the demand for wood pulps is increasing particularly in the production of traditional and new packaging materials, household and sanitary papers, textiles, fluff pulp and novel fibre uses. This development more than offsets the declined demand for wood in production of printing and writing papers, the demand for which is projected to decline globally. The same kind of wood raw material is also used in the production of boards, like OSB and particle boards. While there is some competition over wood fibre between the forest industries and the energy sector, the production of the former is not much affected. Yet, the pulpwood prices increase some due to increased competition. The production and consumption of solid wood products, sawn wood and plywood increase considerably as well, and this eases the supply of sawmill chips and logging residues. Overall, the model analyses show that the most important increases in the forest industry production will take place outside the EU, because the markets are already relatively mature in Europe.

Knowledge Transfer and Innovation – SP5

WBS of SP5.

Terese Løvås

Leader of Knowledge Transfer and Innovation

Norwegian University of Science and Technology
(Photo: NTNU)

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 and PhD courses in bioenergy on a regular basis based on an initiative from CenBio, as described in the Appendices. Eight master student performed their Master Thesis within CenBio activities in 2015 (see Table 15). CenBio has actively sought collaboration with other Graduate Schools in Norther Europe and links have been made both to Cecost Graduate School (Swedish Centre for Combustion Science and Technology) as well as the Nordic Five Tech (N5T) Alliance.

Approximately 32 PhD candidates have been affiliated with CenBio up to 2015 (see Table 13 and Table 14). 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 2016, and aims to be sustainable also after the Centre'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.

Knowledge transfer and dissemination – WP5.2

Deliverables

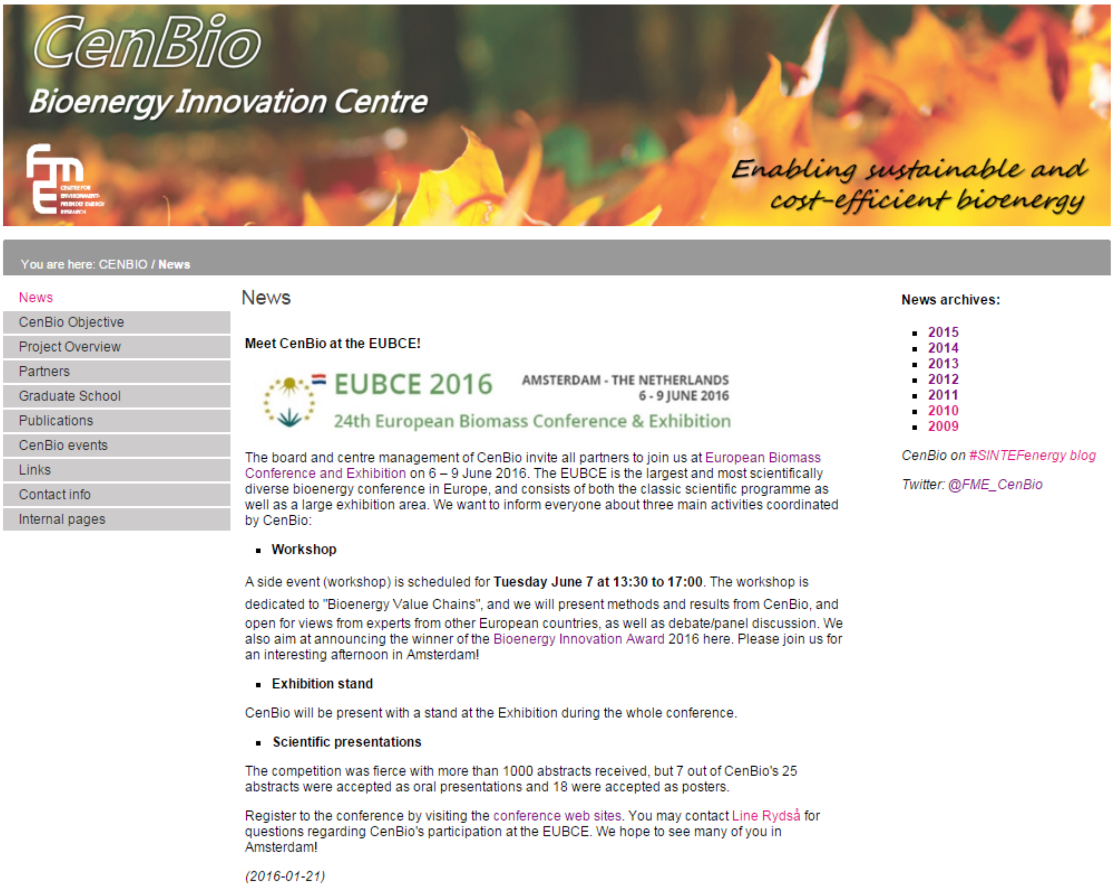
All results from both management and research activities within CenBio are documented in Deliverables, whether they are public or for internal distribution only. The list presented in the Appendices (see Table 25) shows the deliverables that were finalised in 2015.

One of the overall targets for CenBio is to deliver 150 international publications, of which 75 in peer-reviewed journals. Figure 1 shows the current status of the publications in peer-reviewed journals. The list of journal publications from 2015 is given in the Appendices (see Table 19).

CenBio researchers are also present at international conferences (see Table 21), and CenBio researchers are appearing in the media (see list of media contributions, Table 24).

Website: www.CenBio.no

The website was established in June 2009. The website is regularly updated with news relevant to the centre. Lists of public deliverables, hereunder among others Masters' theses and peer-reviewed journal papers, are made available on the webpage. Links locating the documents have been included when they are publicly available online. A screenshot of the homepage is shown in Figure. The page for contact information contains the coordinates of the Centre management.



News

Meet CenBio at the EUBCE!

The board and centre management of CenBio invite all partners to join us at European Biomass Conference and Exhibition on 6 – 9 June 2016. The EUBCE is the largest and most scientifically diverse bioenergy conference in Europe, and consists of both the classic scientific programme as well as a large exhibition area. We want to inform everyone about three main activities coordinated by CenBio:

- **Workshop**

A side event (workshop) is scheduled for **Tuesday June 7 at 13:30 to 17:00**. The workshop is dedicated to "Bioenergy Value Chains", and we will present methods and results from CenBio, and open for views from experts from other European countries, as well as debate/panel discussion. We also aim at announcing the winner of the Bioenergy Innovation Award 2016 here. Please join us for an interesting afternoon in Amsterdam!

- **Exhibition stand**

CenBio will be present with a stand at the Exhibition during the whole conference.

- **Scientific presentations**

The competition was fierce with more than 1000 abstracts received, but 7 out of CenBio's 25 abstracts were accepted as oral presentations and 18 were accepted as posters.

Register to the conference by visiting the conference web sites. You may contact Line Rydså for questions regarding CenBio's participation at the EUBCE. We hope to see many of you in Amsterdam!

(2016-01-21)

Figure 27. CenBio website – www.CenBio.no (screenshot taken 2016-03-09).

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 7) includes more than 35 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.

Eleven innovations have so far been completed and fully implemented, as shown in Figure 29, and given in the list below.

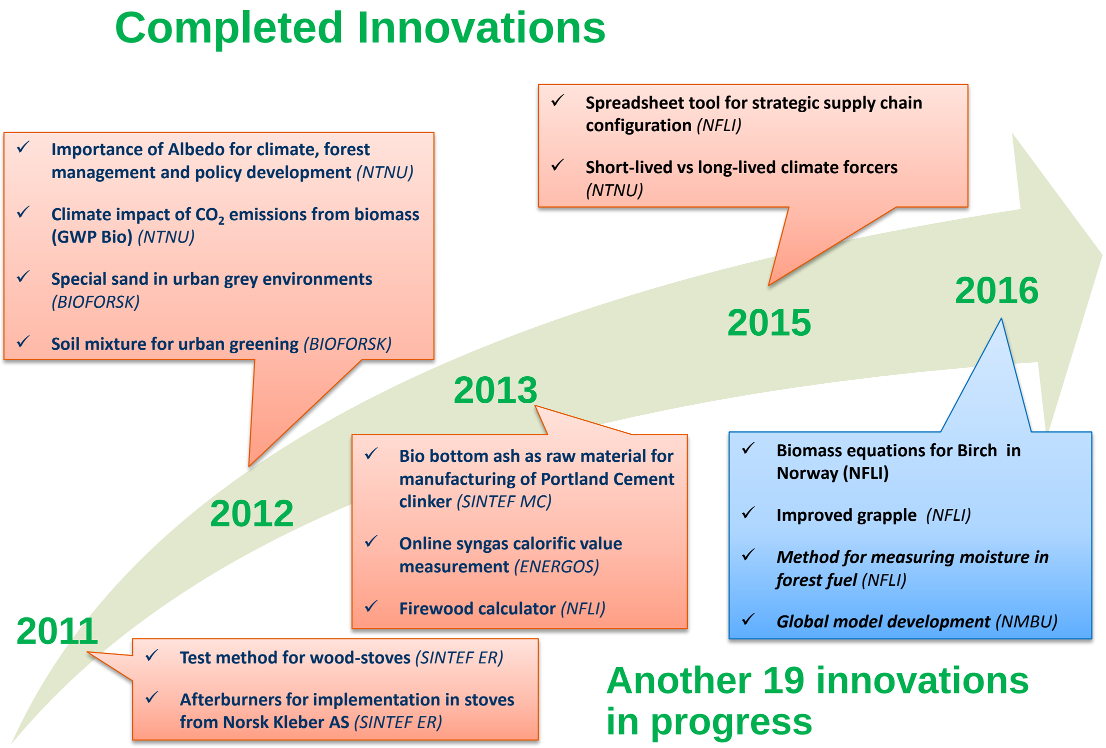


Figure 28: CenBio innovations completed since the beginning of the Centre.

- 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 timesaving (25-50%) compared to existing methods and cost-saving. This is highly relevant for the wood stoves User partners such as Jøtul AS.

- 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.
    - Spreadsheet tool for strategic supply chain configuration for comparison of the economic performance of different supply chain configuration alternatives for wood chip supply.
    - New knowledge is developed on the distinction between climate impact characteristics and degree of reversibility for short-lived vs. long-lived climate forcers.

Another four innovations are nearly completed and are expected to be finalised early in 2016.

Table 7: List of innovations within CenBio (per 31 December 2015)

No	Title	R&D partner	Category of innovation	Status
I1.1.1	*Biomass equations for Birch in Norway*	NIBIO-SOL	Model	Nearly completed
I1.1.2	*Biomass expansion factors for Spruce, Pine and Birch in Norway*	NIBIO-SOL	Model	In progress
I1.2.1	*Cost efficient harvesting and transportation*	NIBIO-SOL	Technology	In progress
I1.2.2	*Improved timbertrucks*	NIBIO-SOL	Technology	Cancelled
I1.2.3	*Improved grapple*	NIBIO-SOL	Technology	Nearly completed
I1.2.4	*Improved bucking procedures*	NIBIO-SOL	Product	Not started
I1.2.5	***Spreadsheet tool for strategic supply chain configuration***	**NIBIO-SOL**	**Concept**	**Completed**
I1.2.6	*Trojan Chip Truck Chipper*	NIBIO-SOL	Product	Not started
I1.3.1	*Tailored fuel mixtures*	SINTEF-ER	Product	In progress
I1.3.2	*Method for measuring moisture in forest fuel*	NIBIO-SOL	Technology	Nearly completed
I1.3.3	***Firewood calculator***	**NIBIO-SOL**	**Service**	**Completed**
I1.4.1	*New fertilizers*	NIBIO-BIOFORSK	Product	In progress
I1.4.2	*Organic NKP fertilizer*	NIBIO-BIOFORSK	Product	In progress
I1.4.3	***Special sand***	**NIBIO-BIOFORSK**	**Product**	**Completed**
I1.4.4	***Soil mixture***	**NIBIO-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
I2.4.1	*Increased energy yields from anaerobic digestion*	NIBIO-BIOFORSK	Subprocess	In progress
I3.1.1	*Clean-burning stoves and fireplaces*	SINTEF-ER	Technology	In progress
I3.1.2	***Afterburners for implementation in stoves from Norsk Kleber AS***	**SINTEF-ER**	**Component**	**Completed**
I3.1.3	***Test method for wood-stoves***	**SINTEF-ER**	**Service**	**Completed**
I3.1.4	*New measurement techniques*	SINTEF-ER	Service	In progress
I3.1.5	*New and revised standards*	SINTEF-ER	Service	In progress
I3.2.1	*Ultra-efficient district heating plants*	SINTEF-ER	New application	CenBio work completed
I3.2.2	*Fossil C measurements*	SINTEF-ER	Technology	CenBio work completed
I3.3.1	*CHP with 100% energy efficiency*	SINTEF-ER	Concept	In progress
I3.4.1	*Low-emission plants*	SINTEF-ER	Concept	In progress
I4.1.1	***Albedo and forests***	**NTNU**	**Concept**	**Completed**
I4.1.2	***Climate impact of CO2 emissions from biomass (GWP bio)***	**NTNU**	**Model**	**Completed**
I4.1.3	***Short-lived vs. long-lived climate forcers***	**NTNU**	**Concept**	**Completed**
I4.2.1	*Recommendations for sustainable harvesting*	NIBIO-SOL	New application	In progress
I4.2.2	*Contribution to development of international standards*	NIBIO-SOL	New application	In progress
I4.2.3	*Environmental performance for biomass value chains*	NIBIO-SOL	New application	In progress
I4.2.4	*Criteria and Indicators for sustainable bioenergy*	NIBIO-SOL	New application	In progress
I4.3 1	*Global model development*	NMBU	Model	Nearly completed
I4.3.2	*National forest sector model for Norway*	NMBU	Model	In progress

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 realise 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 worldwide. The winner in 2013 was Solør Bioenergi, exclusively using contaminated timber as energy source in their 10 MW combined heat and power (CHP) plant. The BIA 2014 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.

The winner in 2015 was Vincent Eijsink, NMBU, for his work within the field of enzyme technology and biogas processes. His scientific research group has an international reputation and are exceptional good at linking basic scientific research and industrial interests.

Figure 29: The winner of Bioenergy Innovation Award 2015 was Vincent Eijsink (NMBU).(Foto:NMBU)

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.

Value Chain Assessment – SP6

Anders Hammer Strømman

Leader of Value Chain Assessment

Norwegian University of Science and Technology
(Photo: NTNU/Flickr)

Value Chain Assessment	SP6/NTNU
Environment and cost characteristics	WP6.1

WBS of SP6.

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 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 utilization 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)

The value chains concept can be seen as a combination of many research activities from CenBio. Per today, CenBio accounts for 30 value chains, grouped by fuel type.

In 2015, the SP6 team has been working on the calibration of the value chains, with a focus on the Waste-to-energy (WtE), the Biogas and the Wood stove value chains. See a representation of the CenBio value chains in Figure 30.

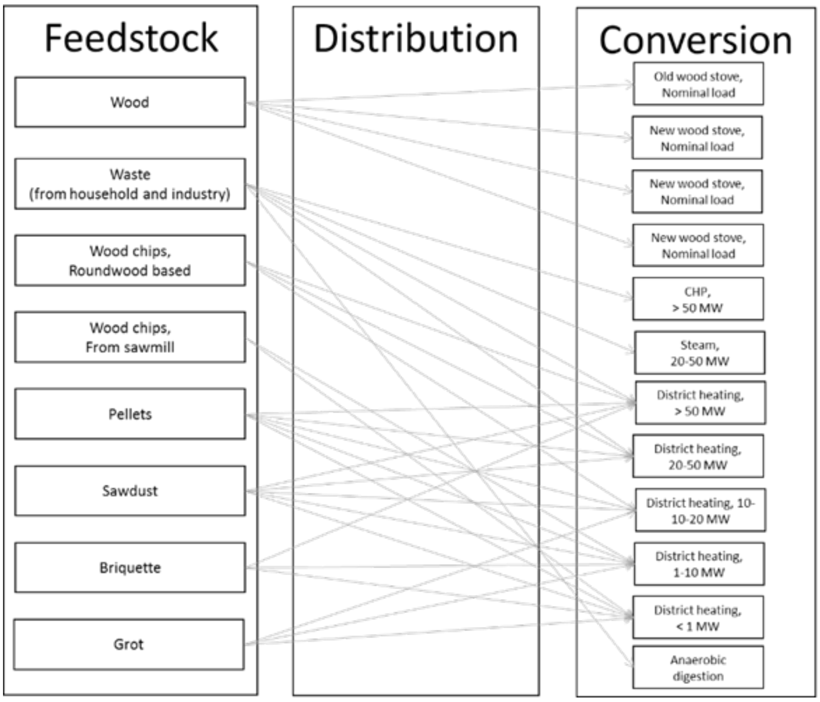


Figure 30. CenBio's 30 value chains.

Waste-to-energy (WtE) value chain

WtE plants have the dual objective to reduce the amount of waste sent to landfill and simultaneously to produce useful energy (heat and/or power). Energy from WtE is gaining steadily increasing importance in the energy mix of several countries. Norway is no exception, as energy recovered from waste currently represents the main energy source of the Norwegian district heating system. Also, 50% of the energy from the WtE sector is accounted for as renewable in Norwegian national statistics, and the sector is thus an interesting candidate in helping to reach the national renewable target.

The Norwegian WtE sector has been a growing industry for the last decade, increasing from a total capacity of 1.3 million tonnes/year in 2010 to 1.7 million tonnes today. The sector currently accounts for 17 plants, spread all across Norway. The average throughput is 90% of the capacity, and the production is around four TWh for district heating networks, in addition to some electricity and process steam for industries located near the plants. Yet several Norwegian WtE plants are currently suffering from low profitability. The main reason is that the processing capacity exceeds the waste produced in the Scandinavian market, where the gate fee is set by the Swedish WtE plants.

A market with excess capacity will put the gate fees under pressure, which is not financially viable in the long run. Two alternatives are either to reduce the processing capacity or to increase the demand for processing capacity. An increase in demand for processing capacity can be achieved by importing waste from markets with insufficient capacity, i.e. countries where the waste would otherwise be landfilled and/or by the insertion of challenging new waste fractions. The latter opportunity has further been investigated by the SP6 team this year, and the insertion — and thus co-combustion — of challenging new waste types such as car fluff, clinical waste and waste wood is assessed.

Life cycle assessment (LCA) is a methodology that has been used extensively within the last decade to evaluate the environmental performance of waste treatment systems and in particular WtE technology such as incineration, and an innovative approach for combining detailed LCA with technology evaluation is used to assess CenBio's WtE value chain (see a schematic drawing of the WtE value chain in Figure 31). Mass transfer coefficients and leaching coefficients are used to trace emissions over the various life-cycle stages from waste logistics to final disposal of the ashes. In addition, the plant model together with actual data on the input waste, air and water emissions and ash composition are used to assess the influence of a change in waste composition on the environmental performance of a WtE plant in a Norwegian context. The Heimdal plant, owned by Statkraft Varme is used as a case study, with close collaboration with the plant owners.

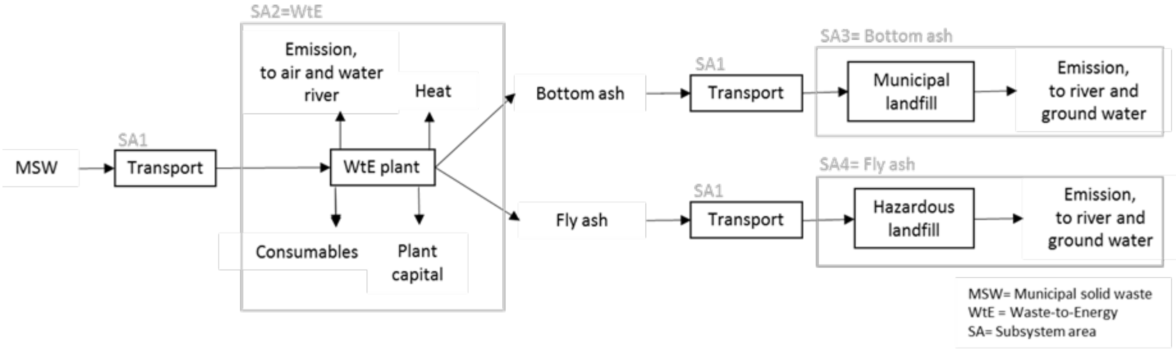


Figure 31. Waste-to-Energy value chain.

The results indicate that the insertion of waste fractions containing a higher amount of heavy metals and fossil CO_2 decreases the overall environmental performance of the plant for an input-based functional unit while the opposite might be true for an output-based functional unit if the new waste fraction has a higher energy content than the common waste mix. We benchmark the environmental performances of our WtE systems to those of fossil energy systems, and we find better performance for the majority of environmental impact categories, including climate change, although some trade-offs exist (e.g. higher impacts on human toxicity potential than natural gas, but lower than coal). In addition, the insertion of challenging new waste fractions is demonstrated to be an option to both cope with the excess capacity of the Norwegian WtE sector and to reach Norway's ambitious political goals for environmentally friendly energy systems.

Wood stove value chain

Improvements in wood stove technology will influence the emission profile, but technology improvements have monetary costs. This year, an integrated analysis considering environmental and economic aspects of two different wood stove technologies (old and new wood stoves with technology for staged air combustion, which reduces particle emissions) operated on different loads (partial and nominal) has been performed. See Figure 32 for an overview of the wood stove value chain.

The environmental analysis is a state-of-the-art LCA, where greenhouse gases as well as other air pollutants affecting human health and having environmental impacts were included. The economic analysis is a cost assessment, analysing cost structures and comparing costs between different wood stove technologies and operation modes. The costs estimated in the analysis are levelised cost of energy, meaning no margins or profits are included. The addition of margins is also analysed, through three levels of margins in addition to the base case. This way, trade-offs between environmental impacts and between environment and economy can be revealed. The analyses are based on empirical and experimental data from the CenBio project partners, describing the current situation in Norway.

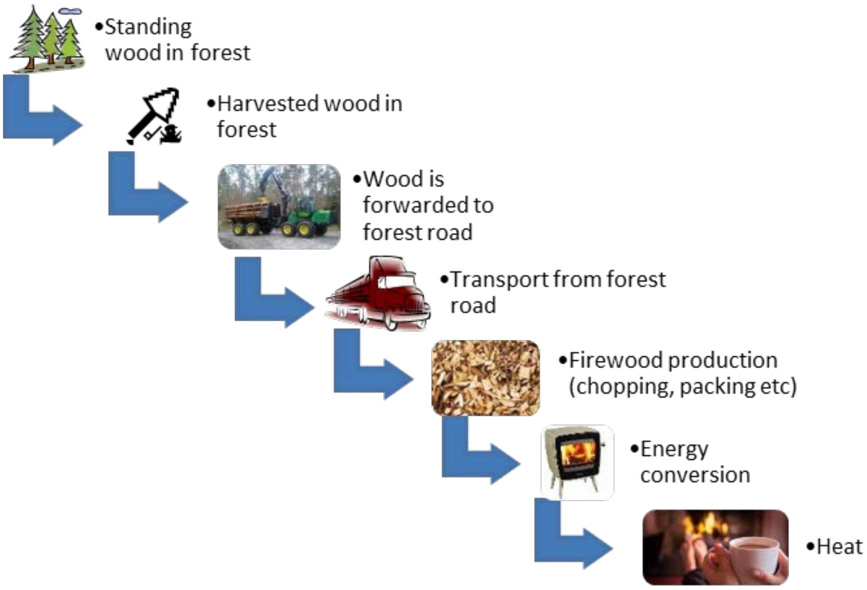


Figure 32. Wood stove value chain.

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

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

Comparing the results from the environmental and economic analysis, we see that there is a clear trade-off in terms of environmental impacts and costs. The cleanest technology is the most expensive and the most polluting is the cheapest. However, the emission reductions are overall substantially higher in per cent than the cost increase. For both environmental impacts and costs, the main hot spots in the value chain are transport and combustion in the wood stove.

Biogas value chain

The production of biogas through anaerobic digestion has grown rapidly over the years, mainly due to the increasing global concerns about mitigation of greenhouse gas emissions from the energy sector and enhancement of energy security. Biogas can be used directly for heating and electricity generation and as a substitute for other fossil fuel applications, e.g. transportation fuel. The potential utilization of the digestate as fertilizer can also reduce dependence on energy intensive mineral fertilizers, to further mitigate greenhouse gas emissions. However, the quantification of the climate change impacts and possible benefits of biogas systems is highly dependent on many factors, such as the type of feedstock, operational practices, energy and materials consumed for cultivation and transport of feedstocks, biogas utilization and demand for transportation and disposal of the process residues. In addition, choices related to the LCA methodology undertaken in the analysis, such as allocation issues, definition of system boundaries and functional units, can also shape the final outcomes. See the biogas value chain in Figure 33.

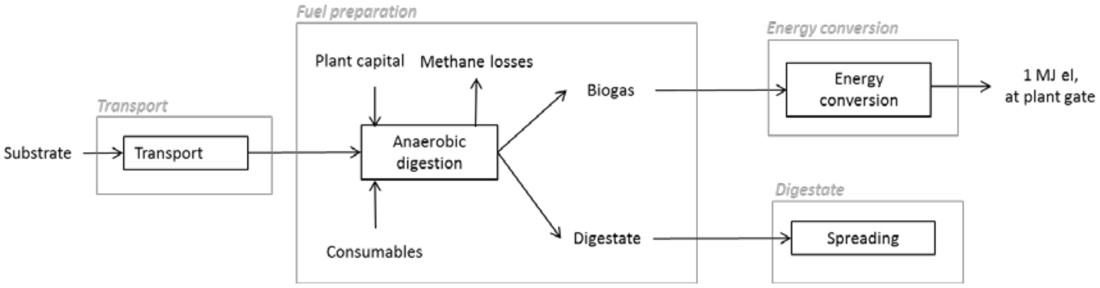


Figure 33. Biogas value chain

In order to prevent possible burden-shifts of concerns, other environmental impact categories than climate change should also be factored in the assessment, such as eutrophication, acidification, toxicity, primary energy consumptions. All these factors have to be considered in the quest for environmental friendly and sustainable energy production from biogas.

To calibrate the biogas value chain to Norwegian context, the SP6 team has been working in close collaboration with the Lindum plant, located in Drammen and which uses Cambi technology.

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, where the highlights from these are reported in the sections below.

Involvement of international partners

The first level of international cooperation in CenBio is direct involvement of international partners in the research and development activities conducted in in the Centre, particularly with our Swedish research partner and User partner Vattenfall. Since the start of CenBio, **Vattenfall (Sweden)**, 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. Many operational challenges may arise when using challenging biomass fuels, both regarding emissions (e.g., NOx) 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 NOx 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.

International conferences and international collaborations

CenBio has been present at a number of international conferences in 2015. Details are listed in Table 21.

The total number of international collaborations resulting in journal publications and peer-reviewed conference papers funded by CenBio is 130 in 2015. Figure 34 shows the status of journal publications resulting from collaborative work involving non-CenBio partners, since the start of the Centre.

The international institutions listed below took part in collaborative research activities with CenBio leading to publications in 2015:

- University of Lisbon (PT)
- University of Natural Resources and Applied Life Sciences (AU)
- Chalmers University (SE)
- University of Ohio (USA)
- University of Copenhagen (DK)
- Belyzaid Consulting & Communication AB (SE)
- Swedish University of Agricultural Sciences – SLU (SE)
- Agricultural University of Iceland (IS)
- Stanford University (USA)
- Commonwealth Scientific and Industrial Research Organisation – CSIRO (AU)
- ETH Zurich (CH)
- United States Environmental Protection Agency (USA)
- Technical University of Denmark (DK)
- Ecole Polytechnique de Montreal (CA)
- University of Texas Health Science Center (US)

- University of Michigan (US)
- University of California (US)
- United Nations Environment Programme - UNEP
- University of Western Sydney (AU)
- European Commission, Joint Research Centre
- Oxford Brookes University (UK)
- UNSW Australia (AU)

Figure 34. Status of external collaborations leading in journal publications within CenBio. Collaborations are counted per collaboration between CenBio partners and non-CenBio partners (i.e. one publication can for example be counted three times, once for collaboration with non-European organisation, and twice more for collaboration with two Norwegian organisations).

CenBio has in 2015 also had an international outreach by including the four members of the **Advisory Board (AB)** in discussions and recommendations to the Centre.

Visiting researchers to and from CenBio

CenBio has welcomed 10 visiting researchers, including the one sin 2015 hown in Table 10. Some of those researchers has been visiting on a regular basis.

Six CenBio researchers in total have visited other countries for at least one month, including one in 2015 (see Table 11). In the period August 2014-January 2015 Eva Brod had a 6-month stay at ETH in Zürich, Switzerland, which resulted in a journal paper with the researchers she collaborated with (see also section for WP1.4).

International researcher's networks

CenBio is funding active participation in international researcher's networks, such as European Energy Research Alliance (EERA) Bioenergy Joint Programme (BJP), and International Energy Agency (IEA), in order to position Norway and in particular bioenergy activities, central both at European and international levels. NTNU is also chairing the global warming task force of the UNEP-

SETAC life-cycle initiative.

Various International Energy Agency (IEA) Bioenergy tasks with involvement of CenBio staff are listed in Table 8.

Table 8: Participation in IEA Bioenergy activities from staff of CenBio.

IEA Bioenergy Task #	Task title	Task member	Representative
Task 32	*Biomass Combustion and Co-firing*	02 SINTEF-ER	Øyvind Skreiberg
Task 33	*Thermal Gasification of Biomass*	02 SINTEF-ER	Roger A. Khalil / Judit Sandquist
Task 36	*Integrating Energy Recovery into Solid Waste Management Systems*	02 SINTEF-ER	Michaël Becidan (WP3.2)
Task 37	*Energy from biogas and landfill gas*	04 NIBIO-BIOFORSK	Tormod Briseid
Task 38	*Greenhouse gas balances of biomass and bioenergy systems*	03 NTNU	Anders Strømman / Francesco Cherubini (WP4.1)
Task 40	*Sustainable International Bioenergy Trade - Securing Supply and Demand*	01 NMBU	Birger Solberg Erik Trømborg
Task 43	*Biomass feedstocks for energy markets*	05 NIBIO-SOL	Bruce Talbot / Simen Gjølsjø

In addition, researchers from CenBio have participated in international standardisation work (CEN, in WP3.1).

Recruitment

The research within CenBio is mainly performed by permanent employees at the research institutes and the universities (see Table 9). In some cases, doctoral and postdoctoral researchers have been recruited to perform research within CenBio. A list of such researchers is given in Table 12, Table 13 and Table 14.

Appendices

A. Personnel

Key Researchers

Table 9: Key staff members who spent more than 10% of their time in CenBio in 2015.

Name	Affiliation	Univ. degree	Sex	Position within own organisation
Odd Jarle Skjelhaugen	NMBU	PhD	M	*Centre Director, Professor*
Tron Haakon Eid	NMBU	PhD	M	*Professor*
Paolo Borges	NMBU	PhD	M	*Researcher*
Svein Jarle Horn	NMBU	PhD	M	*Professor*
Alexander Moiseyev	NMBU	PhD	M	*Researcher*
Gregory Latta	NMBU	PhD	M	*PhD candidate*
Berit Lindstad	NMBU	PhD	F	*Researcher*
Per Kristian Rørstad	NMBU	PhD	M	*Researcher*
Birger Solberg	NMBU	PhD	M	*Professor*
Marie Bysveen	SINTEF-ER	PhD	F	*Vice President Research*
Gonzalo del Alamo Serrano	SINTEF-ER	PhD	M	*Research Scientist*
Mette Bugge	SINTEF-ER	MSc	F	*Research Scientist*
Roger Khalil	SINTEF-ER	PhD	M	*Research Scientist*
Rajesh S. Kempegowda	SINTEF-ER	PhD	M	*Research Scientist*
Berta Matas Güell	SINTEF-ER	PhD	F	*Senior Research Scientist*
Einar Jordanger	SINTEF-ER	MSc	M	*Project Manager*
Alexis Sevault	SINTEF-ER	PhD	M	*Research Scientist*
Øyvind Skreiberg	SINTEF-ER	PhD	M	*Chief Research Scientist*
Liang Wang	SINTEF-ER	PhD	M	*Research Scientist*
Line Rydså	SINTEF-ER	MSc	F	*Research Scientist*
Michaël Becidan	SINTEF-ER	PhD	M	*Senior Research Scientist*
Judit Sandquist	SINTEF-ER	PhD	F	*Research Scientist*
Anders H. Strømman	NTNU	PhD	M	*Professor*
Terese Løvås	NTNU	PhD	F	*Professor*
Francesco Cherubini	NTNU	PhD	M	*Research Scientist*
Tian Li	NTNU	PhD	M	*Postdoctoral fellow*
Xiaoke Ku	NTNU	PhD	M	*Postdoctoral fellow*
Carine Lausselet	NTNU	MSc	F	*Research Scientist*
Eva Brod	NIBIO-BIOFORSK	MSc	F	*PhD candidate*
Linn Solli	NIBIO-BIOFORSK	PhD	F	*Research Scientist*
Tormod Briseid	NIBIO-BIOFORSK	PhD	M	*Head of Department*
Nicholas Clarke	NIBIO-SOL	PhD	M	*Senior Research Scientist*
Aaron Smith	NIBIO-SOL	PhD	M	*PhD candidate*

Simen Gjølsjø	NIBIO-SOL	MSc	M	*Senior Adviser*
Helmer Belbo	NIBIO-SOL	PhD	M	*Research Scientist*
Eirik Nordhagen	NIBIO-SOL	MSc	M	*Research Scientist*
Rasmus Astrup	NIBIO-SOL	PhD	M	*Research Director*
Bjarte Arne Øye	SINTEF-MC	PhD	M	*Research Scientist*
Håkon Kassman	VRD	MSc	M	*Research Scientist*

Visiting Researchers

Table 10: Visiting researchers from other countries in 2015.

Name	Position	Affiliation	Nationality	Duration of stay
Ester Barta-Rajnai	*PhD student*	Hungarian Academy of Sciences	Hungarian	Aug-Sept 2015

CenBio researchers in research exchange abroad

Table 11: CenBio researchers in research exchange abroad in 2015.

Name	Visiting	Country	Duration of stay
Eva Brod	Institute of Agricultural Sciences, Department of Environmental Systems Science at ETH Zürich	Switzerland	Aug 2014 - Jan 2015

Postdoctoral Researchers

Table 12: List of postdoctoral researchers working in the Centre in 2015.

Name	Sex	Affil.	Topic/Research area	Source of funding	Period in the Centre
Xiaoke Ku	M	NTNU	*Thermochemical conversion of biomass for heat and power production - reactor modelling*	CenBio	2012-2015
Tian Li	M	NTNU	*Thermochemical conversion of biomass for heat and power production – particle and kinetic modelling*	CenBio	2015-2017

PhD Students

Table 13: PhD students, both CenBio-funded and associated, working within CenBio in 2015.

Name	Sex	Nationality	Affil.	Topic/Research area	Source of funding	Duration
Walid Mustapha	M	Denmark	NMBU	*The role of bioenergy in the future Nordic energy system*	RCN	2014-2017
Nevena Misljenovic	F	Serbia	NMBU	*Torrefaction and addition of alternative raw materials in biomass pelletization*	NMBU	2014-2016

Live Heldal Hagen	F	Norway	NMBU	*Microbiology and enzymology of anaerobic digestion*	RCN	2015-2017
Ivan Dragicevic	M	Croatia	NMBU	*Harmful component in digestate from biogas plants*	RCN	2015-2018
Jon Gustav Kirkerud	M	Norway	NMBU	*Integrating wind power, small hydro power and bioenergy in the future smart energy system*	RCN	2014-2016
Eli Sandberg	F	Norway	NMBU	*Flexible interplay between thermal energy and the power system*	RCN	2015-2017
Tuva Grytli	F	Norway	NTNU	*Value Chain assessment of bioenergy*	CenBio WP6.1	2013-2016
Silje Skår	F	Norway	NMBU	*Modelling ecological impacts from increased harvesting in Norwegian forests*	25% CenBio WP4.2 / RCN	2009-2016
Kristian Fjørtoft	M	Norway	NMBU	*Technology for farm-scale biogas plants*	NMBU	2009-2016
Eva Brod	F	Germany	NMBU/ Bioforsk	*Organic waste resources and wood ash as fertiliser, phosphorus flows and stocks in the food system*	50% CenBio WP1.4/ RCN	2012-2016
Kolbeinn Kristjansson	M	Norway	NTNU	*Stable heat release from batch combustion of wood*	StableWood (KPN Project)	2012-2016
Kathrin Weber	F	Norway	NTNU	*Modelling of biocarbon production processes*	BioCarb+ (KPN Project)	2014-2017
Inge Haberle	F	Germany	NTNU	*Numerical simulations of the transient behavior of wood log decomposition and combustion*	WoodCFD (KPN project)	2015-2018

Table 14: Completed PhD theses linked to the Centre (per 2015-03-01).

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

2011	Helmer Belbo	M	Norway	*Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees*	Linnaeus University	Rolf Björheden	Linnaeus University, Sweden
2012	Tore S. Filbakk	M	Norway	*Fuel quality of forest biomass intended for chips and pellets: the influence of raw material characteristics, storage and handling*	NMBU	Olav Høibø	NMBU
2012	Dhandapani Kannan	M	India	*Study of Second Generation Biofuels in Internal Combustion Engines*	RCN	Johan E. Hustad	NTNU
2012	Ehsan Houshfar	M	Iran	*Experimental and numerical studies on two-stage combustion of biomass*	KRAV (CenBio In-kind Project)	Terese Løvås	NTNU
2012	Liang Wang	M	China	*Effect of Additives in Reducing Ash Sintering and Slagging in Biomass Combustion Applications*	RCN	Johan E. Hustad	NTNU
2013	Maria M. Estevez	F	Uruguay	*Improving the anaerobic digestion of lignocelluloses and organic wastes: effects of steam explosion, co-digestion and digestate recirculation*	RCN	John Morken	NMBU
2013	Shuling Chen Lillemo	F	China	*Consumers and bioenergy: the effects of behavioural factors on households' heating consumption choice in Norway*	RCN	Mette Vik	NMBU
2013	Geir Skjevrak	M	Norway	*Wood pellets utilized in the commercial and residential sectors – an in-depth study of selected barriers for increased use*	Statoil/ own funding	Johan Einar Hustad	NTNU
2014	Geoffrey Guest	M	Canada	*The climate change impacts from biogenic carbon in products across time*	CenBio WP4.1	Anders H. Strøm-man	NTNU
2014	Dmitry Lysenko	M	Russia	*On numerical simulation of turbulent flows and combustion*	CenBio WP2.1	Ivar S. Ertesvåg	NTNU
2014	Paulo Jorge de Almeida Borges	M	Portugal	*Improved models and methods for solving temporal and spatial harvest activities in forest planning*	CenBio WP1.1	Tron Eid	NMBU
2015	Dhruv Tapasvi	M	India	*Experimental studies on biomass torrefaction and gasification*	CenBio WP2.1	Khanh-Quang Tran	NTNU
2015	Ruth Heidi Samuelsen Nygård	F	Norway	*The potential of molten salts as heat transfer media in fast pyrolysis of wood*	NMBU	Espen Olsen	NMBU

2015	Ellen Soldal	F	Norway	*Integrating life cycle assessment and forest modelling for environmental and economic assessment of forest based bioenergy in Norway*	10% CenBio WP4.2, 90% RCN	Birger Solberg	NMBU
2015	Aaron Smith	M	USA	*Characterizing individual tree biomass for improved biomass estimation in Norwegian forests*	CenBio WP1.1/ RCN	Andreas Brunner	NMBU
2015	Quang Vu Bach	M	Vietnam	*Wet Torrefaction of Biomass - Production and Conversation of Hydrochar*	20% CenBio WP2.1 / STOP (KNP Project)	Khanh-Quang Tran	NTNU

Master degrees

Both NTNU and NMBU were providing courses on Bioenergy at Master level in 2015. Some details about the master's level courses in place in 2015 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:	**NTNU – TEP4212: Gas Cleaning and Emission Control for Stationary Combustion and Gasification**
Level:	Master, 7.5 credits
Objective:	After the course the students will have competence on combustion and emission regulations as well as emission sampling and measurement.
Frequency:	Annually, Fall term.
Students:	20 students in Autumn 2015
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**
Level:	Master, 10.0 credits
Objective:	A candidate who has completed this course should have a thorough knowledge of business and socio- economic aspects related to bioenergy production, and effects on the carbon cycle and climate from the use of bioenergy.

Frequency:	Annually
Activities:	Lectures, exercises, 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: - The natural and socio-economic conditions for forestry in the Nordic countries and the forestry practices that are special to that region; - 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.

Course:	**NMBU-FYS375 Energy technology, Lab**
Level:	Master, 10 credits
Objective:	After the course you will understand important energy conversion from its source form (sun, biomass, wind, elevated water) into a useful form (light, movement, comfort)
Frequency:	Annually
Activities:	Theory preparation, laboratory work, data analysis and report writing

Table 15: M.Sc. thesis in the Centre in 2015.

Name	Sex	Title of thesis	Adviser	Institution
Kristin Johansen	F	*Investeringskostnader og brukererfaringer ved lokale varmesentraler*	Erik Trømborg	NMBU
Christoffer Midthun	M	*Teknologier for sesonglagring av termisk energi - Mulige teknologier for sesonglagringlagring av spillvarme fra avfallsforbrenningsanlegg i Norge*	Monica Havskjold	NMBU
Henrik Huseby	M	*Biogas upgrading: Techno-Economic Evaluation of Different Technologies Based on Norwegian Potential of Raw Materials*	Jorge M Marchetti	NMBU
Sigmund Havn	M	*Korleis få til ein fordelaktiv bruk av biovarme til veksthus i Rogaland?*	Anders Lunnan	NMBU
Tord Ståle N. Storbækken	M	*Varmepumper i hushald - Analyse av endringar i effektforbruket hos hushald med panelomnar og vedfyring ved installasjon av ulike typar varmepumper*	Monica Havskjold	NMBU
Andreas Arnmann Nilsen	M	*Fleksibilitet for fremtiden - Nettariffenes rolle i forhold til elkjelbruk i norske fjernvarmeanlegg*	Torjus Folsland Bolkesjø	NMBU

Christina Skaatan	F	*Når er det realistisk at hele fjernvarmesektoren i Norge kan bli 100% fornybar?*	Monica Havskjold	NMBU
Svetlana Wik	F	*Holdninger til fornybar energi fra avfall hos beboere i Oslo og Bærum*	Odd Jarle Skjelhaugen	NMBU

B. Accountancy

A detailed accounts report for 2015 was submitted to RCN in February 2016. The main financial figures are repeated in this annual report.

Budget

Table 16 shows the anticipated overall budget for CenBio over eight years. The total costs are estimated at NOK 268.565 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.

Table 16: CenBio overall budget.

(MNOK)	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Plan	
Total	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
268.565	27.738	38.594	39.291	38.012	30.072	32.355	29.862	31.641	1.000

Accounts 2015

Total costs reported from the partners in 2015 amounts to NOK 29.862 million, of which NOK 26.895 million from Research partners and NOK 2.967 million from corporate partners. The funding from RCN amounts to 50 % of the total costs.

Funding

Table 17: Funding from various sources 2015.

Source	NOK million
The Research Council	15.000
Research partners	7.391
User partners	7.470
Total	**29.862**

Costs

Table 18: Reported costs from various partners 2015.

Type	NOK million
Research partners	26.895
User partners	2.967
Equipment	0.000
Total	**29.862**

C. Publications

All types of publications produced within CenBio in 2015 are listed in Table 24. Below some specific publications are listed in separate tables. In these tables the earlier terms NFLI and BIOFORSK are used for simplicity.

Journal Papers

Table 19: List of journal papers published in 2015

Title	Author(s)	Affiliation	Journal
Characterization of ashes from Pinus Sylvestris forest biomass	Janka Dibdiakova, Liang Wang, Hailong Li	NFLI	Energy Procedia
Norwegian waste products as alternative phosphorus fertilisers to ryegrass (Lolium multiflorum) Part II: Predicting P fertilisation effects by chemical extraction	Eva Brod, Anne Falk Øgaard, Trond Knapp Haraldsen and Tore Krogstad	Bioforsk, NMBU	Nutrient Cycling in Agroecosystems
Norwegian waste products as alternative phosphorus fertilisers to ryegrass (Lolium multiflorum) Part I: Inorganic P species affect fertilisation effects dependent on soil pH	Eva Brod, Anne Falk Øgaard, Eddy Hansen, David Wragg, Trond Knapp Haraldsen and Tore Krogstad	Bioforsk, NMBU, UiO	Nutrient Cycling in Agroecosystems
Impact of maximum opening area constraints on profitability and biomass availability in forestry – a large, real world case	Paulo Borges, Even Bergseng, Tron Eid and Terje Gobakken	NMBU	Silva Fennica
The effects of site productivity in forest harvest scheduling subject to green-up and maximum area restrictions	Paulo Borges, Isabel Martins, Even Bergseng, Tron Eid and Terje Gobakken	NMBU, University of Lisbon	Scandinavian Journal of Forest Research
Effects of Particle Shrinkage and Devolatilization Models on High-Temperature Biomass Pyrolysis and Gasification	Ku, X., Li, T., Løvås, T.	NTNU	Energy & Fuels
CFD-DEM simulation of biomass gasification with steam in a fluidized BEd reactor	Ku, Xiaoke; Li, Tian; Løvås, Terese	NTNU	Chemical Engineering Science
S-Cl-Na-K chemistry during MSW gasification: A thermodynamic study	Becidan, Michael; Houshfar, Ehsan; Wang, Liang; Lundstrøm, Petter; Grimshaw, Anthony	SINTEF ER, Energos	Chemical Engineering Transactions
The effect of a combined biological and thermo-mechanical pretreatment of wheat straw on energy yields in coupled ethanol and methane generation	Theuretzbacher F, Blomqvist J, Lizasoain J, Klietz L, Potthast A, Horn SJ, Nilsen PJ, Gronauer A, Passoth V, Bauer A.	University of Natural Resources and Applied Life Sciences , SLU, NMBU, Cambi AS	Bioresource Technology
Harnessing the potential of LPMO-containing cellulase cocktails poses new demands on processing conditions	Müller, Gerdt; Varnai, Aniko; Johansen, KS; Eijsink, Vincent; Horn, Svein Jarle	NMBU, Chalmers University (SE)	Biotechnology for Biofuels

Dry and wet torrefaction of woody biomass - A comparative study on combusiton kinetics	Bach, Quang Vu, Tran, Khanh-Quang	NTNU	Energy Procedia
Wet torrefaction of forest residues - Combustion kinetics	Bach, Quang Vu, Tran, Khanh-Quang	NTNU	Energy Procedia
Accelerating wet torrefaction rate and ash removal by carbon dioxide addition	Bach, Quang Vu; Tran, Khanh-Quang; Skreiberg, Øyvind	NTNU, SINTEF ER	Fuel Processing Technology
Effects of wet torrefaction on pyrolysis of woody biomass fuels	Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg, Thuat T. Trinh	NTNU, SINTEF ER	Energy
Upgrading biomass fuels via wet torrefaction: A review and comparison with dry torrefaction	Bach, Quang Vu; Skreiberg, Øyvind	NTNU, SINTEF ER	Renweable & Sustainable Energy Reviews
Norwegian Waste-to-Energy (WtE) in 2030: Challenges and opportunities	Becidan, Michael; Wang, Liang; Fossum, Morten; Midtbust, Hans-Olav; Stuen, Johnny; Bakken, Jon Iver; Evensen, Egil	SINTEF ER, Statkraft, Energos, EGE Oslo, Hafslund	Chemical Engineering Transactions
Predicting NOx emissions from wood stoves using detailed chemistry and computational fluid dynamics	Bugge, Mette; Skreiberg, Øyvind; Haugen, Nils Erland L; Carlsson, Per; Seljeskog, Morten	SINTEF ER	Energy Procedia
Numerical simulations of staged biomass grate fired combustion with an emphasis on NOx emissions	Bugge, Mette; Skreiberg, Øyvind; Haugen, Nils Erland L; Carlsson, Per; Houshfar, Ehsan; Løvås, Terese	SINTEF ER, Energos, NTNU	Energy Procedia
Batch combustion of logs in wood stoves – Transient modelling for generation of input to CFD modelling of stoves and thermal comfort simulations	Øyvind Skreiberg, Morten Seljeskog, Laurent Georges	SINTEF ER, NTNU	Chemical Engineering Transactions
Making Sense of the Minefield of Footprint Indicators	B. Ridoutt, P. Fantke, S. Pfister, J. Bare, A.-M. Boulay, F. Cherubini, R. Frischknecht, M. Hauschild, S. Hellweg, A. Henderson, O. Jolliet, A. Levasseur, M. Margni, T. McKone, O. Michelsen, L. Milà i Canals, G. Page, R. Pant, M. Raugei, S. Sala, E. Saouter, F. Verones, and T. Wiedmann	NTNU, CSIRO, TU Denmark, ETH Zürich, US EPA, Ecole Polytechnique de Montreal, University of Texas, University of Michigan, University of California, UNEP, University of Western Sydney, EC JRC, Oxford Brookes University, UNSW Australia	Environmental Science and Technology

Quantifying surface albedo and other direct biogeophysical climate forcings of forestry activities	Bright, R. M., Zhao, K., Jackson, R., Cherubini, F.	NTNU, Univ Ohio, Stanford	Global Change Biology
Journal paper on harvesting effects on soil organic carbon Influence of different tree-harvesting intensities on forest soil carbon stocks in boreal and northern temperate forest ecosystems	Nicholas Clarke, Per Gundersen, Ulrika Jönsson-Belyazid, O. Janne Kjønaas, Tryggve Persson, Bjarni D. Sigurdsson, Inge Stupak, Lars Vesterdal	NFLI, University of Copenhagen, Belyazid Consulting & Communication AB, Swedish University of Agricultural Sciences, Agricultural University of Iceland	Forest Ecology and Management

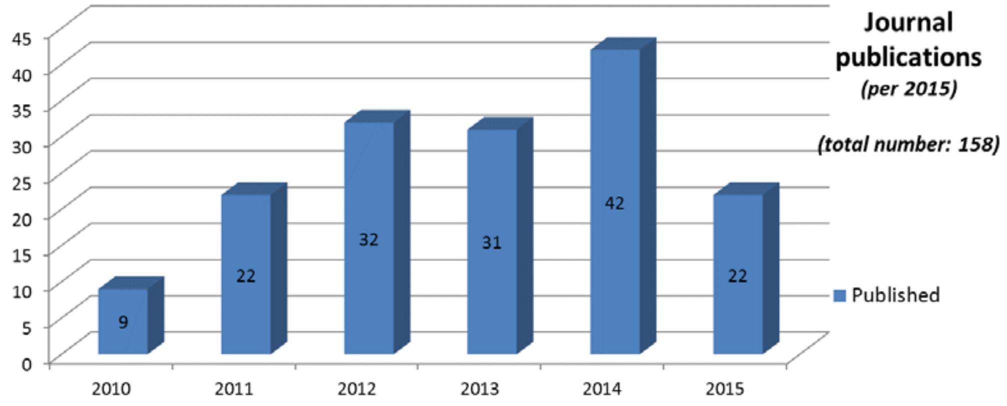


Figure 35: Status of peer-reviewed journal papers published within CenBio.

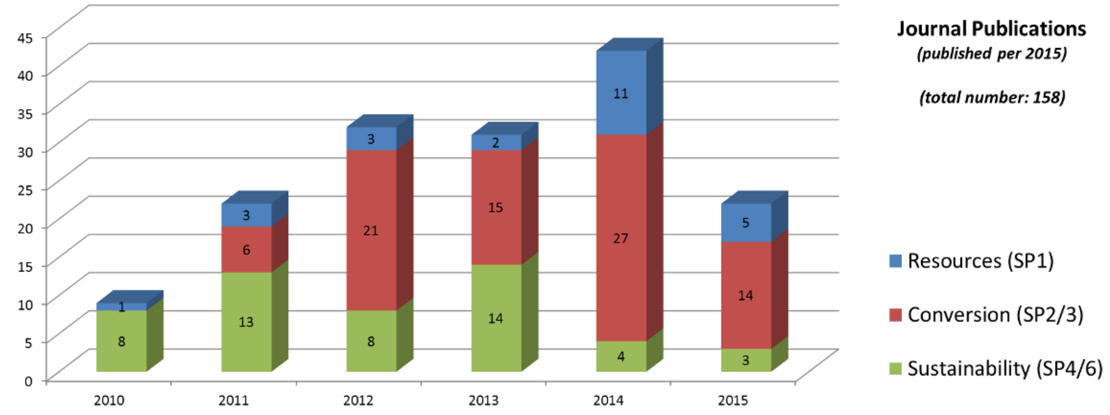


Figure 36: Status of journal publications per sub-project.

Published Conference Papers

There were no published conference papers in 2015 for CenBio.

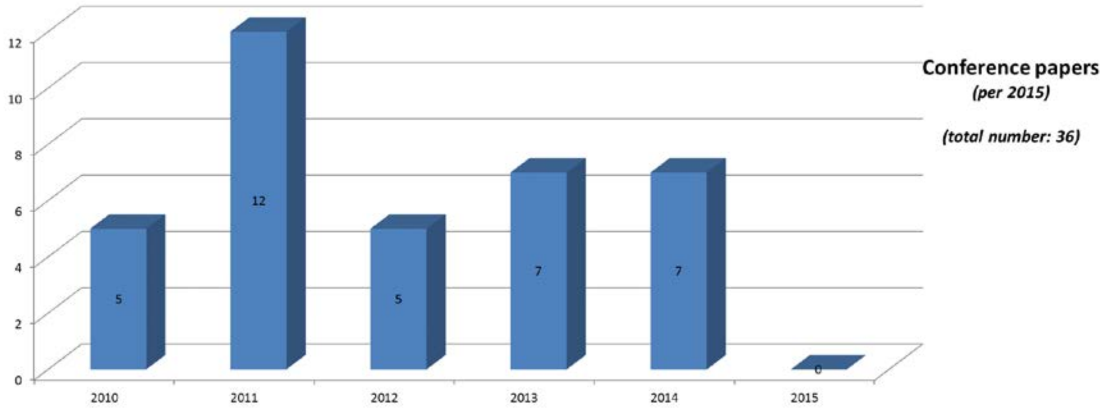


Figure 37. Status of published conference papers within CenBio.

Conference and Scientific Presentations

Table 20: List of conference and scientific presentations given in 2015

Title	Author(s)	Affiliation	Conference
Energimeldingen innspill fra CenBio	Petter E. Røkke	SINTEF ER	Innspillsmøtet for Energimeldingen, OED, 09.12.2015, Oslo
Bioenergy research in the rest of the world, seen by Claes Tullin	Claes Tullin	SP	CenBio Days 2015, 17-19 March 2015, Hell
Bioenergy research in the rest of the world, seen by Pat Howes	Pat Howes	Ricardo-AEA	CenBio Days 2015, 17-19 March 2015, Hell
Bioenergy research in the rest of the world, seen by Marcel van Berlo	Marcel van Berlo	Dutch Ministry of Infrastructure and Environment	CenBio Days 2015, 17-19 March 2015, Hell
Bioenergy research in the rest of the world, seen by Arto Timperi	Arto Timperi	Comatec	CenBio Days 2015, 17-19 March 2015, Hell
Progress and status of the Centre, and opportunities for the future	Berta Matas Güell, Odd Jarle Skjelhaugen	SINTEF ER, NMBU	CenBio Days 2015, 17-19 March 2015, Hell
Presentation for NVE: CenBio Foresight process	Line Rydså	SINTEF ER	Lunsjseminar, NVE
Wood ash: An alternative fertiliser for agriculture	Eva Brod and Trond Knapp Haraldsen	Bioforsk	CenBio Days 2015, 17-19 March 2015, Hell

Sustainable forest-based bioenergy – present situation and future challenges	Berit H Lindstad	NMBU	CenBio Days 2015, 17-19 March 2015, Hell
Will Norwegian wood chips for district heating meet the new world-wide ISO-standard?	Simen Gjølsjø	NFLI	CenBio Days 2015, 17-19 March 2015, Hell
Results from research on anaerobic digestion	Tormod Briseid	Bioforsk	CenBio Days 2015, 17-19 March 2015, Hell
S-Cl-Na-K chemistry during MSW gasification: a thermodynamic study	Michaël Becidan	SINTEF ER	ICheaP12, 19-22 May 2015, Milan
A novel approach for estimating the hydrophobicity of solid biofuels based on contact angle measurements	Nevena Mišljenović, Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg, Reidar Barfod Schüller, Carlos Salas-Bringas	NTNU	Presented at 23rd European Biomass Conference and Exhibition, 1-4 June 2015, Vienna, Austria.
Standardization work with woodstoves	Morten Seljeskog	SINTEF ER	CenBio Days 2015, 17-19 March 2015, Hell
Norwegian Waste-to-Energy (WtE) in 2030 - Challenges and Opportunities	Michael Becidan	SINTEF ER	CenBio Days 2015, 17-19 March 2015, Hell
Poster: Norwegian WtE in 2030	Michaël Becidan	SINTEF ER + WtE partners	ICheaP12, 19-22 May 2015, Milan
Impacts of forest bioenergy and policies on the forest sector in Europe – What do we know?	Birger Solberg, Lauri Hetemäki, A. Maarit I. Kallio, Alexander Moiseyev, Hanne K. Sjølie	NMBU, Metla/Luke	CenBio Days 2015, 17-19 March 2015, Hell
Influence of different tree-harvesting intensities on forest soil carbon stocks in boreal and northern temperate forest ecosystems	Nicholas Clarke, Per Gundersen, Ulrika Jönsson-Belyazid, O. Janne Kjønaas, Tryggve Persson, Bjarni D. Sigurdsson, Inge Stupak, Lars Vesterdal	NIBIO, Univ. of Copenhagen, Belyazid Consulting & Communication, SLU, Agricultural Univ. of Iceland	Towards a Sustainable Bioeconomy, 21-23 October 2015, Barcelona, and Managing Forests to Promote Environmental Services, 3-5 November 2015, Copenhagen
Acidity and forest harvesting in Norway	Nicholas Clarke	NIBIO	Forestry and acidity related issues in Finland, Norway and the UK, 10 September 2015, Uppsala

Soil quality indicators to assess forest management impacts	Inge Stupak, Karin Hansen, Eva Ring, Karsten Raulund-Rasmussen, Nicholas Clarke, Andis Lazdins, Iveta Varnagiryte-Kabasinskiene, Kestutis Armolaitis, Ingeborg Callesen	Univ. of Copenhagen, IVL, Skogforsk, NIBIO, SILAVA, Lithuanian Research Centre for Agriculture and Forestry	Managing Forests to Promote Environmental Services, 3-5 November 2015, Copenhagen
CAR-ES – Water the first 10 years	Lars Högbom, Leena Finér, Nicholas Clarke, Martyn Futter, Per Gundersen, Ari Laurén, Samuli Launiainen, Eva Ring	Skogforsk, Luke, NIBIO, SLU, Univ. of Copenhagen	Managing Forests to Promote Environmental Services, 3-5 November 2015, Copenhagen
Soil carbon sequestration in Nordic forestry: influences of changed land-use and management	Lars Vesterdal, Nicholas Clarke, Bjarni D. Sigurdsson, Helena M. Stefánsdóttir, O. Janne Kjønaas, Per Gundersen, Inge Stupak, Teresa G. Bárcena, Lars P. Kiær	Univ. of Copenhagen, NIBIO, Agricultural Univ. of Iceland	Managing Forests to Promote Environmental Services, 3-5 November 2015, Copenhagen
Standardisation linked to bioenergy in Norway and neighbouring countries	Hilde Aarefjord	Standard Norge	CenBio Days 2015, 17-19 March 2015, Hell
Disentangling the climate change contributions of CO_2 emissions from global forest bioenergy	Francesco Cherubini	NTNU	Our Common Future under Climate Change, Paris (France) 7-10 July 2015
Biogenic carbon emissions and climate impact dynamics	Francesco Cherubini	NTNU	Invited Speaker at "Environmental use of wood resources", Discussion Forum on Life Cycle Assessment, 4th December 2015, Zurich, Switzerland
From research to market	Vidar Andreassen	Innovasjon Norge	CenBio Days 2015, 17-19 March 2015, Hell
Burnt-out innovations – A tortuous pathway from scientific results to marketable products	Trond Knapp Haraldsen	Bioforsk	CenBio Days 2015, 17-19 March 2015, Hell
SP6 – Value chain assessments – Results and work in progress	Francesco Cherubini, Tuva Grytli, Carine Grossrieder, Gonzalo del Alamo Serrano, Line Rydså	SINTEF ER, NTNU	CenBio Days 2015, 17-19 March 2015, Hell

Integrated economic and environmental assessment of heat production from wood stoves in Norway	Tuva Grytli, Geoffrey Guest, Carine Lausselet, Francesco Cherubini, Ryan Bright, Anders Hammer Strømman, Per Kristian Rørstad, Helmer Belbo, Rasmus Astrup, Øyvind Skreiberg, Morten Seljeskog, Franziska Goile	NTNU, NMBU, NIBIO, SINTEF-ER	Life-Cycle Management (LCM) Conference, Bordeaux (France) 30/8-2/9 2015. Poster presentation
Integrating life cycle assessments in the Norwegian Waste-to-Energy sector	Lausselet C., del Alamo Serrano G., Becidan M., Guest G., Cherubini F., Grytli T., Rydså L., Strømman A.H.	NTNU, SINTEF-ER	Life-Cycle Management (LCM) Conference, Bordeaux (France) 30/8-2/9 2015. Poster presentation
Ny studie av verdikjeden for ved	Per Kristian Rørstad, Tuva Grytli, Geoffrey Guest, Carine Lausselet, Francesco Cherubini, Ryan Bright, Helmer Belbo, Rasmus Astrup, Øyvind Skreiberg, Morten Seljeskog, Franziska Goile, Anders Hammer Strømman	NMBU, NTNU, NIBIO, SINTEF-ER	Bioenergidagene, 19.11.2015. Oral Presentation
Sustainability and efficiency in bioenergy production	Lausselet, C.	NTNU	CenBio Workshop-How to ensure bioenergy production in a sustainable and efficient manner in Norway? – From strategies to actions. 22 September 2015. Gardemoen. Oral presentation
SP6 Waste-to-Energy value chain: Summary of the results	Lausselet, C., del Alamo Serrano G., Becidan M., Cherubini F., Rørstad P.K, Strømman A.H.	NTNU, SINTEF-ER, NMBU	CenBio Strategic Days 2015. Trondheim, 28-29 October 2015. Oral presentation

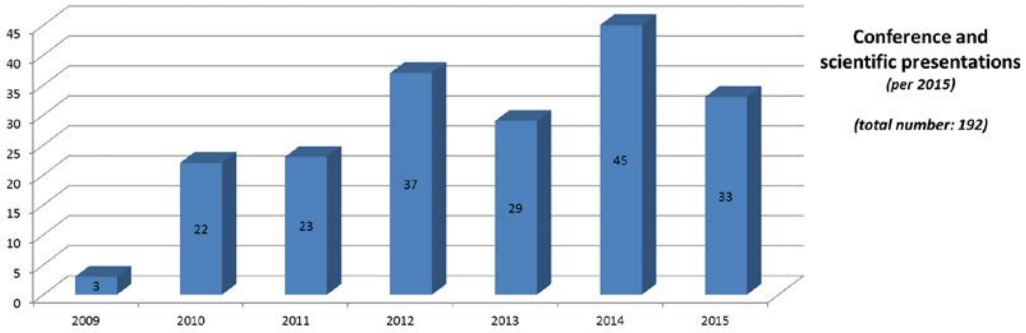


Figure 38: Status of conference and scientific presentations performed within CenBio.

Chapters in books

There were no chapters in book from CenBio in 2015. There were five PhD Theses and five Master's Theses delivered in 2015, see Table 14and Table 15.

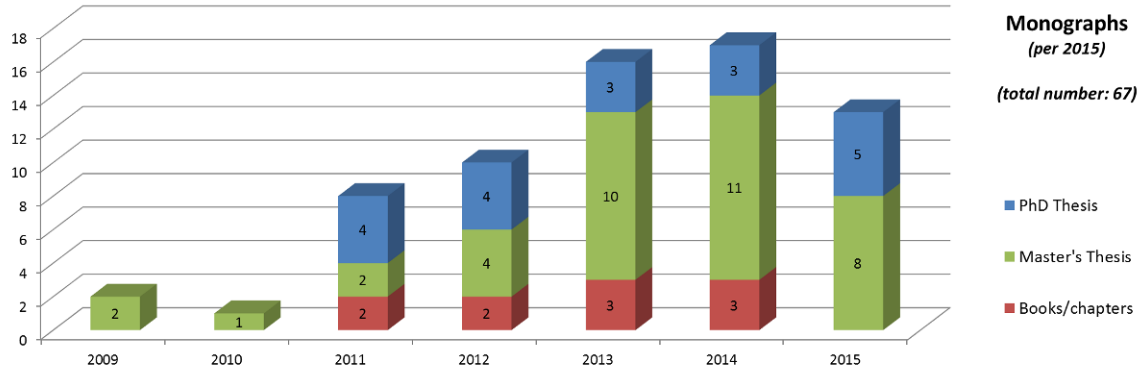


Figure 39: Status of monographs published within CenBio.

Reports

Table 21: List of reports finalised in 2015

Title	Author(s)	Lead partner	Classification
Annual work Plan 2016	Einar Jordanger	SINTEF-ER	Restricted
Progress Report 1 2015	Alexis Sevault	SINTEF-ER	Restricted
Progress Report 2 2015	Alexis Sevault	SINTEF-ER	Restricted
Accounts Report 2014	Einar Jordanger	SINTEF-ER	Restricted
Annual Report 2014	Alexis Sevault, Einar Jordanger	SINTEF-ER	Public
Biomass expansion factors for spruce, pine and broad leaved trees in Norway	Tron Eid, Knut Ole Viken, Rasmus Astrup	NMBU	
Vurderinger omkring organiske miljøgifter i aske og fiskeslam	Erik Joner, Janka Dibdiakova, Trine Ytrestøyl, Trond Knapp Haraldsen	Bioforsk	Public
Nyttig bruk av organisk avfall. Vurderinger av organisk gjødsel, jordforbedringsmidler og ingredienser i jordblandinger	Trond Knapp Haraldsen og Bente Føreid	Bioforsk	Public
Co-combustion of hazardous hospital waste with MSW	Michaël Becidan	SINTEF-ER	Restricted
Energy storage and low-temperature heat utilization	Rajesh S. Kempegowda, Mette Bugge	SINTEF-ER	Restricted
Long term ChlorOut test	Annika Stålenheim, Mattias Mattsson, Åsa Astervik, Håkan Kassman	VRD	Restricted
Impacts of forest bioenergy and policies on the forest sector in Europe – what do we know?	Birger Solberg, Lauri Hetemäki, A. Maarit I. Kallio, Alexander Moiseyev and Hanne K. Sjølie	NMBU	Public

Collection of journal paper abstracts published within CenBio (Update per March 2015)	Alexis Sevault, Stine Lund Davanger, Bodil J. Sætherskar, Einar Jordanger	SINTEF-ER	Public

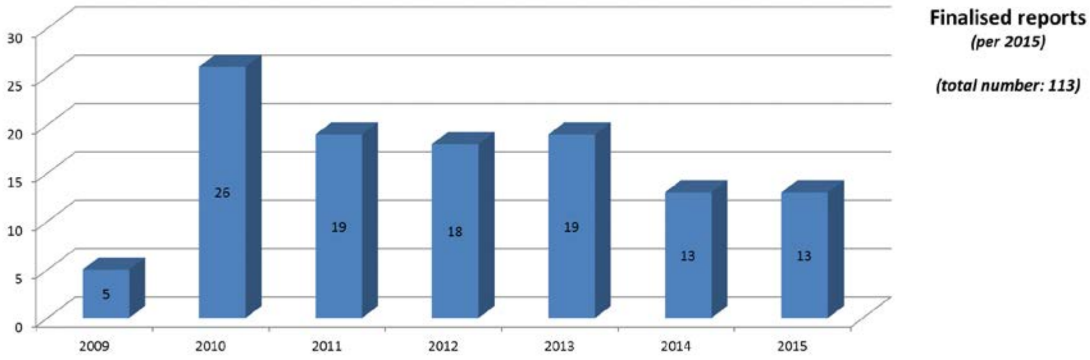


Figure 40: Status of technical reports published within CenBio.

Media contributions

We have listed most of the contributions from CenBio personnel during 2015, mostly in Norwegian media, in Table 23.

Table 22: List of media contributions 2015

Title	Author(s)	Lead partner	Media
Meet CenBio at the EUBCE!	Alexis Sevault	SINTEF ER	SINTEF Energy Blog
Innspill til energimeldingen fra CenBio	Petter E. Røkke	SINTEF ER	SINTEF Energy Blog
SINTEF Energis sluttinnspill til Energimeldingen	Inge Gran	SINTEF ER	SINTEF Energy Blog
Skyggegruppemøte Bioenergi 5. desember 2014	Berta Matas Guell	SINTEF ER	SINTEF Energy Blog
Markedet for skogflis	Simen Gjølsjø	NFLI	NRK Radio P1 Her og Nå
Hvordan finne den beste veden	Simen Gjølsjø	NFLI	TV2 Hjelper deg
Oppvarmet skogsavfall gir mer energi	Øyvind Skreiberg, Roger A. Khalil	SINTEF ER	SINTEF Energy Blog
Hvordan få til bedre energiutnyttelse av avfall i fremtiden?	Michael Becidan	SINTEF ER	SINTEF Energy Blog
Gode råd om vedfyring	Morten Seljeskog	SINTEF ER	NRK P1 Pluss, Frokostradio
Her er "vedfyringens ABC"	Christina Benjaminsen, Øyvind Skreiberg, Morten Seljeskog	SINTEF ER	Gemini.no
Bioenergy and buildings	Skreiberg, Øyvind; Georges, Laurent; Seljeskog, Morten	SINTEF ER, NTNU	Pan European Networks: Government

"Business as usual" er ikke løsningen	Skreiberg, Øyvind; Maltby, Lars Petter; Fladmark, Helene Falck; Gløckner, Ronny; Karlstad, Kristin; Wærnes, Aud	SINTEF ER	Finansavisen
Cheaper heating using environmentally-friendly wood-burning stoves	Benjaminsen, Christina; Skreiberg, Øyvind	SINTEF ER	gemini.no
Miljøvennlig vedfyring gir deg billigere varme	Benjaminsen, Christina; Skreiberg, Øyvind	SINTEF ER	gemini.no
Vi skal ta miljøvennlig vedfyring og vedovnsdesign til nye høyder	Øyvind Skreiberg	SINTEF ER	SINTEF Energy Blog
Tre tips gir skikkelig fyr i peisen	Marit Aaby Vebenstad, Morten Seljeskog	SINTEF ER	klikk.no
Dette må du gjøre nå	Marit Aaby Vebenstad, Morten Seljeskog	SINTEF ER	klikk.no
Best paper award till Lars-Erik Åmand och Håkan Kassman	Håkan Kassman	Vattenfall	Chalmers University website
Hvordan oppnår du optimal trekk og riktig fyring i vedovnen?	Merethe Ruud, Øyvind Skreiberg	SINTEF ER	Teknisk Ukeblad
CenBio Workshop: Virkingsgrader og bærekraftighet	Judit Sandquist, Michael Becidan og Øyvind Skreiberg	SINTEF ER	SINTEF Energy Blog
Fikk innovasjonspris for sitt arbeid med bioenergi	Mette Bugge	SINTEF ER	SINTEF Energy Blog
Innovasjonspris til Vincent Eijsink	Eivind Norum	NMBU	nmbu.no
Alt som kan lages av olje, kan lages av trær	Vincent Eijsink, Svein Jarle Horn, Margareth Øverland	NMBU	Aftenposten-nett
Sats på kildesortering	Svetlana Wik	NMBU	Bærum Budstikke
Ja til energi fra avfall	Svetlana Wik	NMBU	Dagsavisen
Bruk skogen for å nå klimamålene	Odd Jarle Skjehaugen	NMBU	Standard Norge nett
Se hvordan kloakk fra 4,5 millioner amerikanere forvandles til gjødsel og strøm	Pål Jahre Nilsen	Cambi	Teknisk ukebladd nett
Antec Biogass – Ny teknologi: Glem alt du har lært om biogassproduksjon	Egil Andersen	Nibio	Teknisk ukebladd nett
Standarder dokumenterer bærekraften i biodrivstoff	Odd Jarle Skjehaugen	NMBU	Norsk skogbruk

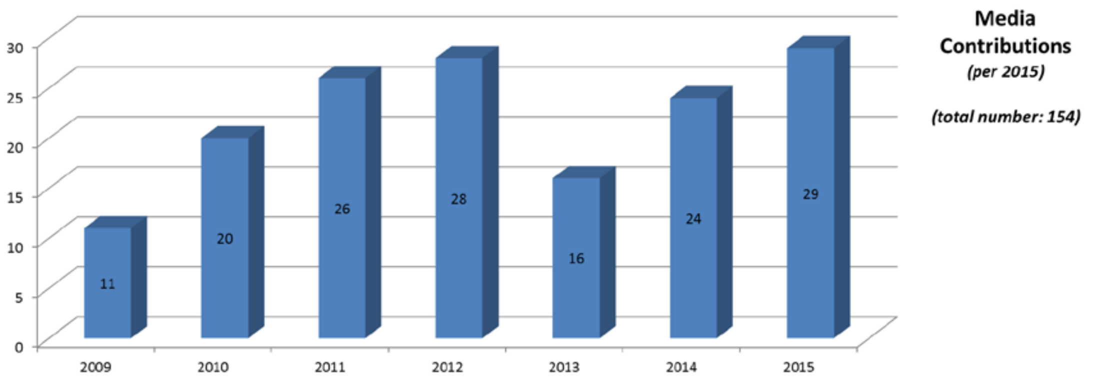


Figure 41: Status of media contributions published within CenBio.

D. Deliverables List

There are a wide variety of deliverables in CenBio (technical report, conference article, journal article, presentation, poster, note).

In Table 24, the deliverables present in the operative Deliverables list for 2015 are shown. In total, ***67*** deliverables were finalised in 2015. 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"

Most deliverables were planned and reported in the Annual Work Plan 2015 (AWP2015), and some where added throughout the year (see "new" in the last column), and some where transferred from 2014, after the AWP2015 was finalised (see "2014" in the last column). Some planned deliverables were cancelled or delayed. The delayed deliverables have been transferred to the 2016 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
- Merged deliverables

*Table 23: List of Deliverables 2015. *: In column "New", "new" stands for new deliverables, while "2014" stands for the deliverables from 2014.*

Del. no.	Deliverable title	Dated	Lead partner	Type	New*
D0.1.1_8	*Annual work Plan 2016*	31.12.2015	**SINTEF-ER**	MR	
D0.1.2_71	*Progress Report 1 2015*	01.06.2015	**SINTEF-ER**	MR	
D0.1.2_72	*Progress Report 2 2015*	01.12.2015	**SINTEF-ER**	MR	
D0.1.3_6	*Accounts Report 2014*	06.02.2015	**SINTEF-ER**	MR	
D0.1.3_7	*Accounts Report 2015*	08.02.2016	**SINTEF-ER**	MR	
D0.1.4_6	*Annual report 2014*	06.03.2015	**SINTEF-ER**	MR	
D0.1.6	*SP0 Abstract to EUBCE*	30.10.2015	**SINTEF-ER**	O	new
D0.1.5_1	*Presentation of the Foresight Process to NVE*	05.06.2015	**SINTEF-ER**	PR	new
D1.1.12	*Biomass expansion factors for spruce, pine and broad leaved trees in Norway*	31.12.2015	**NFLI**	TR	
D1.1.16	*Functions for estimating aboveground biomass of birch in Norway*	01.09.2014	**NFLI**	JP	
D1.1.20	*Functions for estimating belowground and whole tree biomass of birch in Norway*	01.09.2015	**NFLI**	JP	
D1.1.24	*Rapid, Nondestructive Estimation of Forest Understory Biomass Using a Handheld Laser Rangefinder*	31.09.2015	**NFLI**	JP	

D1.1.26	*Optimization algorithms for compacting biomass harvest operations to reduce costs*	05.12.2015	**NMBU**	JP	
D1.1.27	*PhD-thesis and defence Aaron Smith*	31.09.2015	**NFLI/NMBU**	JP	
D1.1.28	*Mapping of biomass extraction – foundation for optimizing utilization*	Cancelled	**NFLI**	JP	
D1.1.28	*Comparing Different Candidate Solution Generators in a Simulated Annealing Approach*	20.08.2015	**NMBU**	CP	
D1.2.13	*Simple decision support tool for strategic evaluation of supply chain alternatives*	09.02.2016	**NFLI**	TR	
D1.2.14	*Joint supply chain evaluation*	Delayed	**NFLI**	TR/JP	
D1.2.15	*Input to SP6 Value Chains*	Delayed	**NFLI**	O	
D1.2.20	*Assessment how various supply chain configurations affect design criteria, options for location and costs of temporary roadside biomass terminals*	Delayed	**NFLI**	TR/JP	
D1.2.22	*Terminal times and influencing variables for chip transport units*	Delayed	**NFLI**	JP	
D1.2.23	*Concept study: A Trojan Chip Truck Chipper*	Delayed	**NFLI**	JP	
D1.2.24	*Status of tools and methods for planning and monitoring woodfuel supply in Norway*	Delayed	**NFLI**	TR/JP	
D1.3.11	*Measuring of moisture content in wood chips with near infrared spectroscopy*	Delayed	**NFLI**	JP	
D1.3.13-2	*Value chain analyses; participation for the development of the work methodology*	Delayed	**NFLI/ SINTEF-ER**	O	
D1.3.19	*Inherent properties in forest residues of Scots pine forest residues harvested in South Norway*	01.05.2015	**NFLI**	TR/JP	2014
D1.3.20	*Inherent properties of Birch biomass in some geographical locations in South Norway*	Delayed	**NFLI/ SINTEF-ER**	JP/TR	
D1.3.21	*Characterization of ashes from Pinus Syvestris forest biomass*	Delayed	**SINTEF-ER/ NFLI**	JP	
D1.3.22	*Alkali release and ash transformation of during thermal conversion of bark fuels*	Delayed	**SINTEF-ER**	JP	
D1.3.23	*Characterization of wood ashes from Birch trees*	Delayed	**NFLI/ SINTEF-ER**	TR	
D1.4.5	*Efficiency of bottom wood ash as K fertiliser to spring cereals and ryegrass*	Dec.15	**Bioforsk/ NMBU**	JP	
D1.4.10	*Norwegian waste products as alternative phosphorus fertilisers to ryegrass (Lolium multiflorum) Part II: Predicting P fertilisation effects by chemical extraction*	15.05.2015	**Bioforsk/ NMBU**	JP	
D1.4.15	*Quality of ash from different combustion technologies*	Delayed	**Bioforsk**	TR	
D1.4.16	*Norwegian waste products as alternative phosphorus fertilisers to ryegrass (Lolium multiflorum) Part I: Inorganic P species affect fertilisation effects dependent on soil pH*	15.05.2015	**Bioforsk**	JP	new
D1.4.17	*Drivers of phosphorus uptake by barley following secondary resource application*	Delayed	**Bioforsk**	JP	new
D1.4.18	*Vurderinger omkring organiske miljøgifter i aske og fiskeslam*	25.06.2015	**Bioforsk**	TR	new
D1.4.19	*Nyttig bruk av organisk avfall. Vurderinger av organisk gjødsel, jordforbedringsmidler og ingredienser i jordblandinger*	26.06.2015	**Bioforsk**	TR	new
D2.1.10_7	*IEA Task 32 activity report 2015*	Continuous	**SINTEF-ER**	O	
D2.1.22	*Detailed Operational Mapping of a Grate Fired Biomass Combustion Plant for Improved Combustion Process Control*	14.12.2015	**NTNU**	JP	2014

D2.1.29	*CFD simulations with the aim of proposing operational improvements for NOx reduction*	Delayed	**NTNU**	JP	
D2.1.30	*Instrumentation: temperature measurements*	Cancelled	**Energos**	O	
D2.1.31_1	*Ash deposits in WtE/BtE plants - EGE Oslo - Klemetsrud*	14.12.2015	**SINTEF-ER/ SINTEF-MC**	CP	
D2.1.31_2	*Ash deposits in WtE/BtE plants - Statkraft Varme - Heimdal*	14.12.2015	**SINTEF-ER/ SINTEF-MC**	CP	new
D2.1.31_1	*Ash deposits-EGE Oslo-Klemetsrud*	21.12.2015	**SINTEF-ER**	CP	new
D2.1.31_2	*Ash deposits-Startkraft Varme-Heimdal*	21.12.2015	**SINTEF-ER**	CP	new
D2.2.11_7	*IEA Task 33 activity report 2015*	Continuous	**SINTEF-ER**	O	
D2.2.18	*S-Cl-Na-K chemistry during MSW gasification: a thermodynamic study*	19.05.2015	**SINTEF-ER**	PR	
D2.2.19	*Syngas modelling for maximum energy content*	Cancelled	**NTNU/ SINTEF-ER**	O (note)	
D2.4.6_7	*Minutes from IEA Task 37 meetings 2015*	Continuous	**BIOFORSK**	O	
D2.4.11	*The effect of a combined biological and thermo-mechanical pretreatment of wheat straw on energy yields in coupled ethanol and methane generation*	01.10.2015	**BIOFORSK**	JP	new
D2.4.20	*AD microbial community structure response to changed feed*	Cancelled	**BIOFORSK**	JP	2014
D2.4.21	*Lignocellolytic substrate*	Cancelled	**NMBU**	JP	2014
D2.4.25	*AD microbial community structure in biogas plants with and without thermic pretreatment of the substrates*	Delayed	**Bioforsk**	JP	
D2.4.26	*Microbial communities in two-phase anaerobic digestion systems*	Delayed	**NMBU**	JP	
D2.5.15	*PhD Defence and Thesis Dhruv Tapasvi "Experimental and Simulation Studies on Biomass Torrefaction and Gasification"*	22.06.2015	**NTNU**	O	new
D3.1.4_7	*Reports from standardization meetings*	Continuous	**SINTEF-ER**	O	
D3.2.6_7	*IEA Task 36 participation*	Continuous	**SINTEF-ER**	O	
D3.2.13	*Bottom ash from WtE: national survey*	10.11.2015	**SINTEF-ER**	O	
D3.2.15	*Norwegian WtE in 2030*	19.05.2015	**SINTEF-ER (+ WtE partners)**	PR	
D3.2.16	*Co-combustion of hazardous hospital waste with MSW*	06.03.2015	**SINTEF-ER**	O (note)	
D3.2.17	*Workshop on bioenergy production*	30.09.2015	**SINTEF-ER**	O	
D3.3.7	*Long term ChlorOut test*	27.02.2015	**VRD**	TR	new
D3.3.8	*Operational experiences from a ChlorOut installation in a BFB boiler*	Delayed	**VRD**	TR	new
D3.3.10	*Aspects on the flue gas chemistry of KCl, NO and CO during injection of ammonium sulphate*	Delayed	**VRD**	CP/JP	new
D3.3.11	*Flue gas chemistry during injection of ammonium sulphate – an experimental approach in a BFB boiler*	29.02.2016	**VRD**	TR	
D3.3.12	*Reduction of chlorine in deposits - Searching for the breaking point*	Delayed	**VRD**	TR	new
D3.3.13	*Energy storage and low-temperature heat utilization for power production*	05.11.2015	**SINTEF-ER**	TR	
D3.4.10	*Operation optimisation for emission minimization: guidelines and proposals for a real plant*	10.02.2016	**SINTEF-ER**	TR	
D4.1.44	*Validation and calibration of emission metrics for forest bioenergy*	Cancelled	**NTNU**	JP	
D4.1.45	*Quantifying surface albedo and other direct biogeophysical climate forcings of forestry activities*	19.06.2015	**NTNU**	JP	

D4.1.46	*Biogenic CO2 as a short-lived climate pollutant: implications and perspectives*	Delayed	**NTNU**	JP	
D4.1.47	*Making Sense of the Minefield of Footprint Indicators*	12.02.2015	**NTNU**	JP	new
D4.2.13-2	*Influence of different tree-harvesting intensities on forest soil carbon stocks in boreal and northern temperate forest ecosystems*	03.07.2015	**NFLI**	PR	
D4.2.18	*Short-term effects of whole-tree harvesting on plant diversity and cover in two Norway spruce forest sites*	01.08.2015	**NFLI**	JP	
D4.2.19	*Report on suggestions for criteria and indicators for sustainable forest harvesting for bioenergy (I4.2.4)*	Delayed	**NFLI**	TR	
D4.2.25	*Nordic/Baltic review of ecological consequences of increased biomass removal from forests for bioenergy*	Delayed	**NFLI**	JP	
D4.2.26	*Acidity and forest harvesting in Norway*	01.09.2015	**NFLI**	PR	new
D4.2.27_1	*Soil quality indicators to assess forest management impacts*	01.11.2015	**NFLI**	PR	new
D4.2.27_2	*CAR-ES – Water the first 10 years (Keynote)*	01.11.2015	**NFLI**	PR	new
D4.3.11	*Conceptual report on what is meant by sustainable bioenergy production, and discussion of corresponding criteria and indicators*	Delayed	**NMBU**	TR	
D4.3.16	*Estimation of the carbon leakage effects of increased harvest in Norway*	Delayed	**NMBU**	JP	
D4.3.22-1	*Impacts of forest bioenergy and policies on the forest sector in Europe – what do we know?*	17.03.2015	**NMBU**	TR	
D4.3.22-2	*Impacts of forest bioenergy and policies on the forest sector in Europe – what do we know? Policy brief*	Delayed	**NMBU**	O	
D4.3.25	*Impacts of subsidies on the future energy prices and competition over fiber*	Delayed	**NMBU**	PT	
D4.3.26-1	*Analysing Norwegian non-industrial forest owners' willingness to supply roundwood and forest residues – basic data description and data representativeness*	Delayed	**NMBU**	TR	
D4.3.27	*A comparative analysis of forest-based bioenergy policies in five European countries*	Delayed	**NMBU**	JP	
D5.1.13	*Development of a course portfolio for joint graduate courses*	Delayed	**NTNU**	O	
D5.1.14	*Organise Graduate School networking event at the CenBio Consortium Days*	18.03.2015	**NTNU +NMBU**	O	
D5.2.18_7	*4 industry workshops*	Continuous	**SINTEF-ER**	O	
D5.2.20_7	*Scientific publishing: 20 scientific papers submitted, 10 conferences papers*	Continuous	**NMBU**	O	
D5.2.21_7	*CenBio website*	Continuous	**SINTEF-ER + NMBU**	O	
D5.2.22_7	*CenBio Days March 2015*	17.03.2015	**SINTEF-ER + NMBU**	O	
D5.2.23_7	*External conferences and presentations: 10 international conferences, seminars and workshops. 10 presentations*	Continuous	**SINTEF-ER + NMBU**	O	
D5.2.24_7	*Popular publishing: 20 popular articles and press news*	Continuous	**NMBU + all WPs**	O	
D5.2.26_7	*CenBio Strategic Day October 2015*	29.10.2015	**SINTEF-ER + NMBU**	O	
D5.2.27	*Decide whether to arrange a CenBio International Conference 2016 or participate in a relevant established annual conference*	01.12.2015	**NMBU + SINTEF-ER**	O	

D5.2.28-1	*Collection of journal paper abstracts published within CenBio (Update per March 2015)*	27.03.2015	**SINTEF-ER**	MR	
D5.3.8-5	*Status of CenBio Innovations, 5th version*	31.12.2015	**SINTEF-ER**	O	
D5.3.10-5	*Extending the CenBio activities - Status*	22.12.2015	**SINTEF-ER**	O	
D5.3.11-5	*Award the 5th Bioenergy innovation award*	08.04.2015	**SINTEF-ER**	O	
D5.3.13	*Fourth innovation workshop*	08.04.2015	**SINTEF-ER**	O	
M6.1.1	*Data for second batch of results*	24.11.2015	**NTNU / NMBU**	PR	
M6.1.2	*Data for third batch of results*	23.11.2015	**NTNU / NMBU**	PR	
D6.2.1	*Outcomes of the economic assessment at single value chain level*	Delayed	**NMBU**	TR	
D6.2.2	*Outcomes of the economic assessment of the bioenergy system at Norway national level*	Delayed	**NMBU**	TR	
D6.2.3	*Outcomes of the economic assessment of promising value chains*	Delayed	**NMBU**	TR	
D6.3.1	*Outcomes of analysis at single value chain level and Norwegian level.*	Delayed	**NTNU**	PS	
D6.3.2	*Environmental assessment of the current Norwegian bioenergy system.*	Delayed	**NTNU**	JP	
D6.3.3	*Bioenergy value chain case studies.*	Delayed	**NTNU**	JP	
D6.3.4	*Life cycle assessment of bioenergy production from orchards woody residues in Northern Italy*	03.10.2015	**NTNU**	JP	new

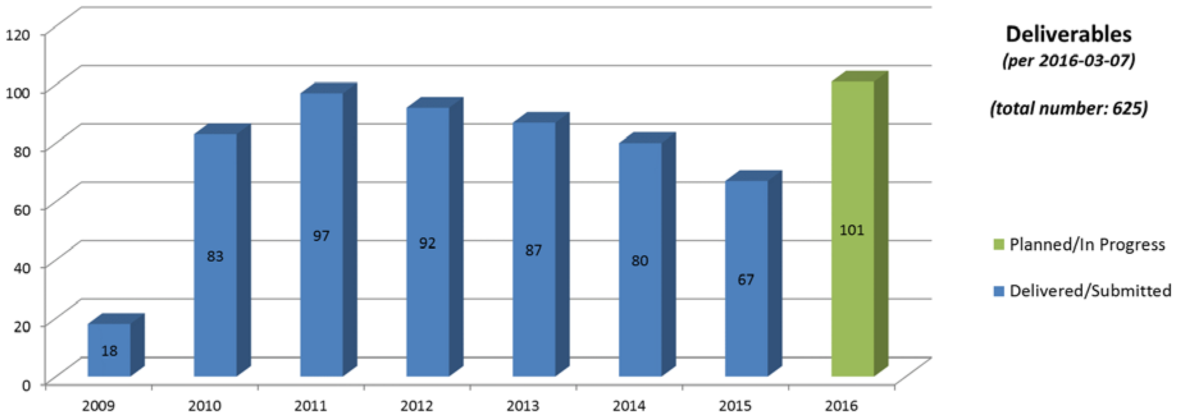


Figure 42: Status of deliverables achieved within CenBio.

E. List of events organised by CenBio*

*: Table 25 does not include the more regular meetings organised 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. 3 per year)
- General Assembly (once a year during CenBio Days)
- Regular meetings with partners
- RCN Meetings (kontaktmøter, etc…)

Table 24: List of events organised by CenBio from 2009 to 2015.

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
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 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, 05 June 2014	SP0	2014
CenBio Strategic Days 2014, Ås Campus / Gardemoen, 29-30 October 2014	SP0	2014
CenBio Strategic Days 2015, Trondheim, 28-29 October 2015	SP0	2015

CenBio Days 2015, Trondheim/Hell, 17-19 March 2015	SP0	2015
5th Bioenergy Innovation Award, Scandic Hell Hotell, Hell, 17 March 2015	SP5	2015
CenBio Workshop: How to ensure bioenergy production in a sustainable and efficient manner in Norway? – From strategies to actions, Gardermoen, 22 September 2015	SP3	2015

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 25: Short names of partners.

No	Short name	Entity legal name
01	**NMBU**	Norges miljø- og biovitenskapelige universitet **(Host institution)**
02'	**SINTER-ER**	SINTEF Energi AS **(Coordinating institution)**
03	**NTNU**	Norges teknisk-naturvitenskapelige universitet NTNU
04	**NIBIO-BIOFORSK**	Norsk institutt for bioøkonomi (Bioforsk)
05	**NIBIO-SOL (NFLI)**	Norsk institutt for bioøkonomi (Norsk institutt for skog og landskap)
06	**SINTEF-MC**	Stiftelsen SINTEF
07	**VRD**	Vattenfall AB
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 2015
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

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