Annual Report 2012

CenBio - Bioenergy Innovation Centre

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

CONTENTS

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

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

EDITORIAL

Norway has the ambition of strong growth within the bioenergy sector. The industrial production units are rather small, so there is a need for research and training across a larger part of the value chain than for the rest of the energy sector – from resources, logistics, economics and technology. CenBio has had a successful first four-year period strengthening the important collaboration between the R&D groups within resources and logistics at Ås, and the R&D groups within technology in Trondheim – and together with the user partners. This collaboration is essential, and will form the basis for an even stronger national research platform during the remaining of CenBio and beyond.

Examples of outstanding achievements in the first years are:

1. **A new LCA method** to account for the environmental impact and CO_2 emissions from biomass combustion. This work resulted in the Laudise Medal being awarded to Professor Anders H. Strømman, NTNU, in 2011. His work on the albedo effect and his role as co-author of the novel IPCC report are worth mentioning.

2. Improved **methods for estimating marginal costs of forest biomass production** for bioenergy.

3. The **first empirically based estimates** for Norway on how extractions of forest residues may impact the long-term productivity of forests.

4. A **novel sector model** including forestry and forest industries, in addition to various types of bioenergy value chains. This model enables the analysis of how international financial and policy measures may impact the Norwegian biomass market and the competition for wood fiber between traditional forest industries and wood-based bioenergy producers.

5. A **new test method for wood stoves**, being both time- and cost-saving, and the development of an afterburner for woodstoves to ensure that Norwegian environmental requirements are adequately met.

6. The feedstock spectrum for **biogas production** has been broadened and their digestibility has been improved. Co-digestion of fish waste, wood fiber waste (rich in lignin) and manure, combined with different ways of pretreatment, seems to increase the overall efficiency.

The high level of our research activities has enabled us to position CenBio on the international scene and collaborate with a number of other international research institutions. In addition, our results brought us the opportunity to start a new work package in 2013, dedicated to the assessment of the bioenergy value chains.

Marie Bysveen
Centre Coordinator
SINTEF Energi AS
Coordinating Institution
(photo: Gry Karin Stimo)

Odd Jarle Skjelhaugen
Deputy Centre Coordinator
Universitetet for miljø- og biovitenskap
Host Institution
(photo: Elin Judit Straumsvåg)

VISION AND GOAL

The vision of CenBio is to develop the basis for a sustainable, cost-effective bioenergy industry in Norway, in order to achieve the national goal of doubling bioenergy use by 2020.

Bioenergy Vision 2020

	TWh - 2008		
	Input	Efficiency	Output
Wood/pellet stoves	7	0.6	4.2
District heat	2.7	0.85	2.3
Wood industry	4.4	0.85	3.7
CHP – heat	~ 0	0.6	~ 0
CHP – power		0.2	
Power	~ 0	0.4	~ 0
Biogas	~ 0	0.5	~ 0
SUM	**14.1**		**10.2**

	TWh - 2020		
	Input	Efficiency	Output
Wood/pellet stoves	12	0.85	10.2
District heat	6	0.9	5.4
Wood industry	5	0.9	4.5
CHP – heat	4	0.65	2.6
CHP – power		0.3	1.2
Power	1	0.5	0.5
Biogas	2	0.7	1.4
SUM	**30**		**25.8**

Figure 1: Bioenergy Vision 2020 for 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.

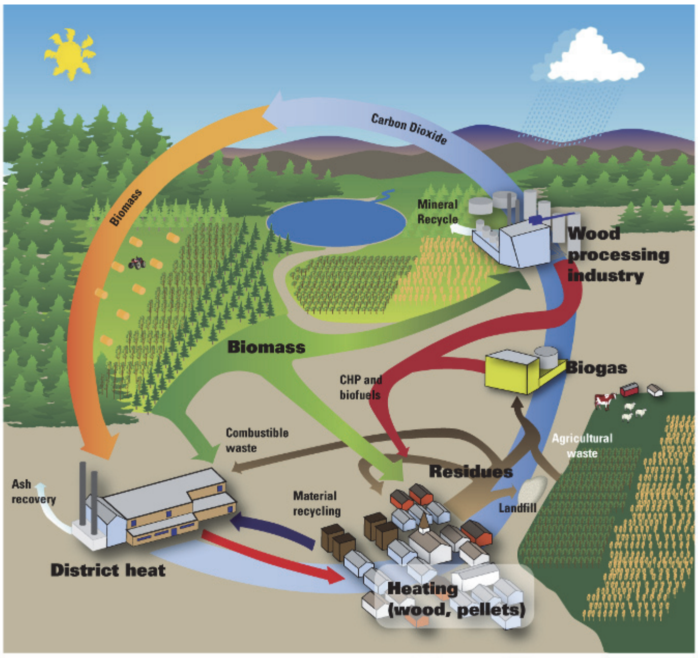

Figure 2: CenBio scope.

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.

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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 RCN and the host institution UMB. 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 Plans (AWP)

AWP 2012

The final version of AWP 2012 was sent to RCN on 31 December 2011, after inputs from all partners and approval from the Executive Board (EB).

AWP 2013

The deadline for the AWP 2013 was exceptionally advanced to 30 November 2012, since it is one of the documents required for the mid-term evaluation of CenBio by the RCN. Similarly to AWP 2012, the document received inputs from all partners and was approved by the EB.

Joint laboratories

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

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

Biochemical conversion lab

Biogas lab

Torrefaction unit (*Trondheim*)

Figure 3: Joint laboratories. (photos: UMB and SINTEF)

ORGANIZATION AND COORDINATION

The fruitful research activities carried out in CenBio during the first four years brought a significant amount of results and knowledge in most topics related to the bioenergy industry in Norway. The maturity of the Centre enables to take a major step forward and start with a new sub-project (SP6) dedicated to Value Chains Assessment from 2013. We believe that this SP will be essential to concretize CenBio's contributions to the national goal of doubling bioenergy use in Norway by 2020, compared to 2008.

To succeed, this new SP requires a very tight collaboration with all other SPs, and thus between the different research partners and user partners. With, so far, more than 30 CMT (Centre Management Team) meetings, 10 executive board meetings, 3 occurrences of the CenBio Days and the regular direct contacts between SP leaders and the user partners, the management team has well prepared the Centre to tackle this challenge.

As a result of the development of SP6 throughout 2012, together with all CenBio partners, four main value chains have been selected for assessment (see Figure 6):

- Firewood used in residential woodstoves;
- District heating based on upgraded wood and municipal solid waste (MSW);
- Combined heat and power (CHP) plants based on upgraded wood and MSW;
- Biogas from anaerobic digestion (AD) of organic waste and agricultural residues.

Another challenging task for the Centre management in 2012 was to complete the midterm self-evaluation, as requested by the RCN. At the end of the fourth year of activity, each FME Centre has the responsibility to perform a midterm evaluation, which will assess its right to get funding from RCN for the last three years (total of 8 years). A significant part of the resources for the Centre management in 2012 was allocated to this task. In addition, an enhanced cooperation between the management, the research partners and the user partners was required to coordinate this task.

Nevertheless, CenBio considered this task as an opportunity to re-enforce the link between its members, and notably, further detail the action plan for SP6. In addition, the Centre used this chance to produce a supplementary document: "Best of CenBio". The document takes the shape of an 8-page booklet, mainly addressed to the general public, in order to optimize the communication on CenBio activities. It contains the general description and the objectives of the Centre, the list of partners and a selection of five successful collaborations between CenBio researchers and the user partners. The booklet will be officially distributed to the public from March 2013, starting with the site visit by RCN in Ås.

Einar Jordanger
Centre Manager
SINTEF Energi AS
(photo: Gry Karin Stimo)

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Partners

Initially, 26 partners took part in CenBio. Universitetet for miljø- og biovitenskap (UMB) is host institution and SINTEF Energi AS is coordinating institution. The governance structure is further detailed in Figure 4. Three partners left the Centre in 2011 (Xynergo AS, Afval Energie Bedrijft and BioNordic AS).

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

Research partners

UMB, Norwegian University of Life Sciences (**Host institution**)

SINTEF Energy Research (**Coordinating institution**)

NTNU, Norwegian University of Science and Technology

Bioforsk

Norwegian Forest and Landscape Institute

SINTEF Foundation

Vattenfall Research and Development AB (Sweden)

Industry partners (cf. Table 24 for a list of short names)

Akershus Energi AS

Norges Skogeierforbund

Agder Energi AS

Nord-Trøndelag Elektrisitetsverk (NTE) Holding AS

Hafslund ASA

Statkraft Varme AS

Norske Skogindustrier ASA

Norsk Protein AS

Avfall Norge

Norges Bondelag

Oslo Kommune Energigjenvinningsetaten (EGE)

Vattenfall AB, Heat Nordic (Sweden)

Energos AS

Cambi AS

Jøtul AS

Granit Kleber AS

Governance Structure

The governance structure of CenBio (2013), as defined in the Consortium Agreement is shown in Figure 4.

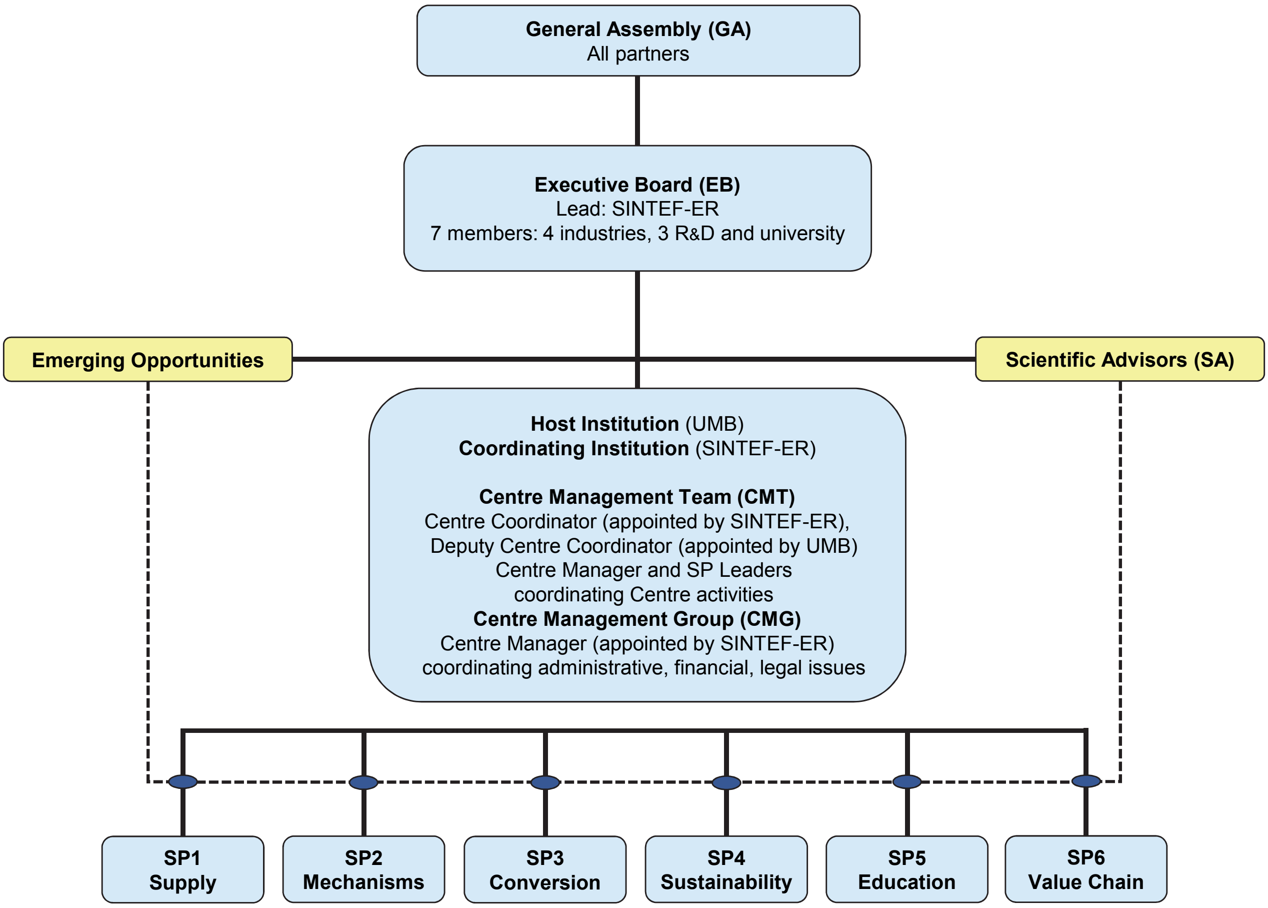

Figure 4: CenBio Governance Structure (2013). SP stands for Sub Project.

The General Assembly (GA) consists of one representative from all partners, and meets physically at least once a year (usually during the CenBio Days). All persons registered as CenBio personnel have access to the CenBio eRoom, where they have access to all produced documents and planned events.

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

Table 1: Executive Board members 2012.

Position	*Name*	*Affiliation*
Chairperson	**Petter Støa**	02 SINTEF-ER
EB Member (Research)	**Arne Bardalen**	05 NFLI
EB member (Research)	**Olav Bolland**	03 NTNU
EB member (Industry)	**Morten Fossum**	13 STATKRAFT
EB member (Industry)	**Rune Dirdal**	17 AVFALLN
EB member (Industry)	**Hans Olav Midtbust**	22 ENERGOS
EB member (Industry)	**Gudbrand Kvaal**	09 SKOGEIER

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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 organizes regular meetings, as required for coordinating the activities in the Centre.

Table 2: Centre Management Team.

Position	Name	Affiliation
Centre Coordinator	**Marie Bysveen**	02 SINTEF-ER
Deputy Centre Coordinator	**Odd Jarle Skjelhaugen**	01 UMB
Centre Manager	**Einar Jordanger** **Alexis Sevault** **Astrid Lilliestråle**	02 SINTEF-ER 02 SINTEF-ER 02 SINTEF-ER
SP1 leader	**Simen Gjølsjø**	05 NFLI
SP2 leader	**Michaël Becidan**	02 SINTEF-ER
SP3 leader	**Øyvind Skreiberg**	02 SINTEF-ER
SP4 leader	**Birger Solberg**	01 UMB
SP5 leader	**Anders H. Strømman**	03 NTNU
SP6 leader	**Anders H. Strømman**	03 NTNU

Scientific Advisors (SA) were appointed in 2010, one for each Sub-Project, except SP0 and SP5. The four Scientific Advisors are shown in Table 3.

Table 3: 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

Work Breakdown structure (WBS)

The technical activities within CenBio are organized in six Sub Projects (SPs), each divided into Work Packages (WPs). A separate SP is defined to separate the management activities from the technical work, under SP0. The WBS is shown in Figure 5.

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

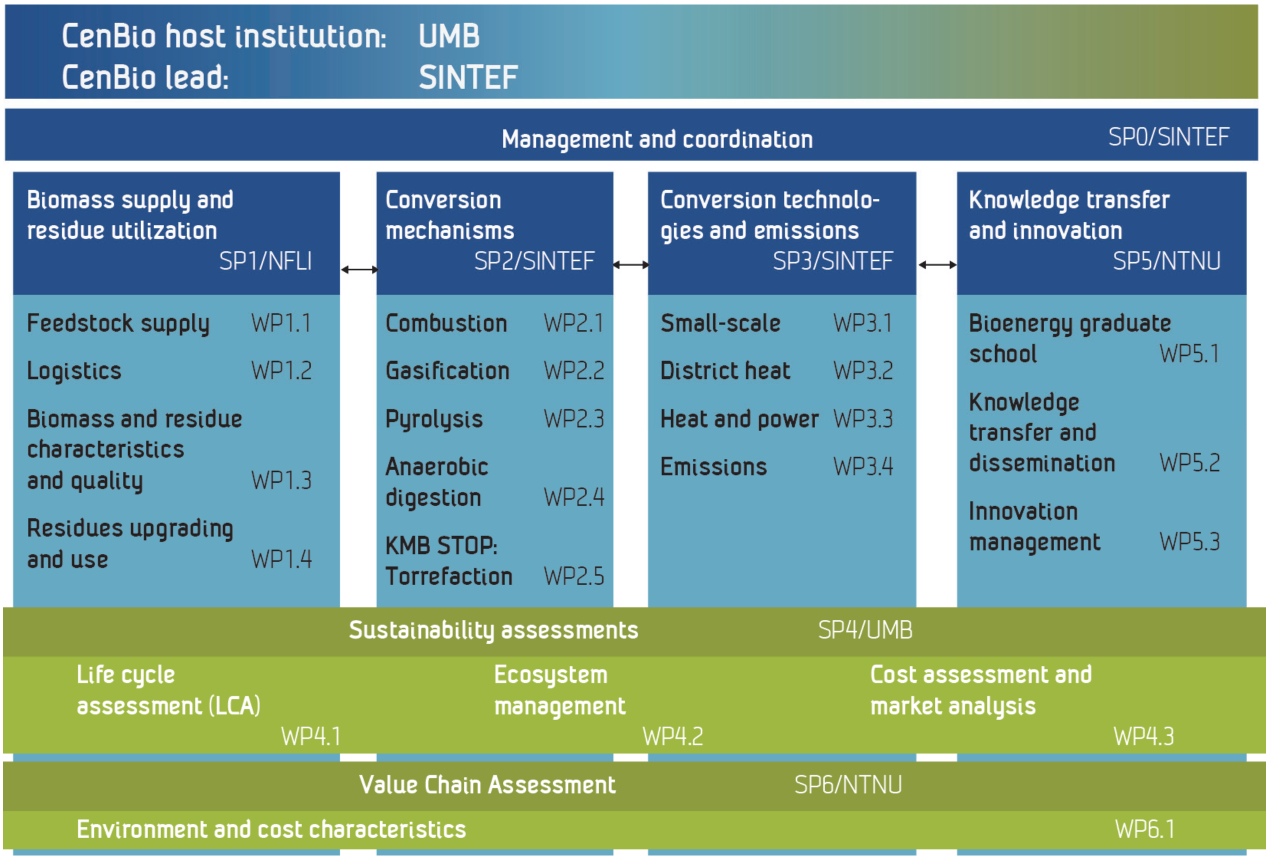

Figure 5: Work Breakdown Structure (2013).

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. In some Work Packages (WP), partners, both from Ås and Trondheim, participate and there is cooperation between different WPs. Such cooperation is to be documented in the annual work plans and annual reports.

The industrial partners also contribute with in-kind research, and in some cases researchers from the universities or research institutes perform research at their installations.

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

Once a year, the Centre invites all partners to attend the CenBio Days. Up to now, this event has been arranged in January in conjunction with the General Assembly, where all partners are expected to participate. In addition, international experts and CenBio Scientific Advisors (SA) are invited to give state-of-the-art presentations.

In 2012, the CenBio Days took place at UMB (Ås) on 18-19 January. Presentations from selected researchers and invited representatives from industrial partners were given in plenary sessions. Special topics, such as bioenergy, forests and climate, were discussed in workshop sessions with subsequent reporting in a plenary session. Two of the four scientific advisors gave keynote presentations about bioenergy R&D.

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One important cooperation activity between the research groups in Ås and Trondheim will have major repercussions during the second half of CenBio: the establishment of SP6 dedicated to the assessment of various bioenergy value chains. The different value chains relevant to the Norwegian bioenergy industry are shown in Figure 6. By nature, SP6 requires a close collaboration both between the research partners and with the different user partners. The cooperation between research groups at Ås an in Trondheim has certainly given added value to the bioenergy research in Norway.

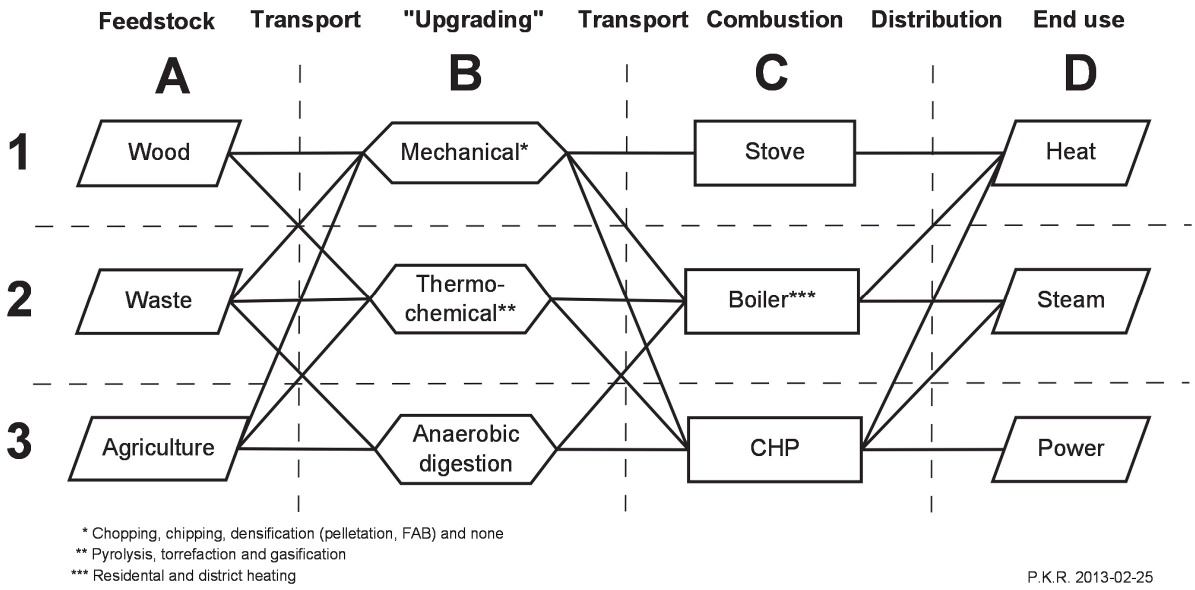

Figure 6: Value chains seen as combinations of research activities from CenBio.

Management and Coordination

General

The overall coordination activities are organized within a separate work package, WP0.1 - Management and Coordination. During 2012, the main activities consisted in reporting costs and progress, arranging coordination meetings, and coordinating the planning of future research activities. Management within each SP or WP is the responsibility of respective SP- and WP leaders. In addition to those usual tasks, SP0 also coordinated the self-evaluation reporting related to the mid-term evaluation from the Research Council of Norway, due on 30 November 2012.

Project management system – the CenBio eRoom

A project management system for CenBio was established in 2009, where all relevant documents are uploaded. Personnel from all partners have access to the CenBio eRoom. By 31 December 2012, more than 100 persons had access to the eRoom. The overall structure of the CenBio eRoom was described in the Annual Report 2011.

Meetings

The Centre Management Team had eleven meetings in 2012, and the Core Management Team met twelve times. The Executive Board had three meetings, in June, September and November, and the General Assembly met on 18 January in Ås. 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, finalized deliverables are documented in the remaining annual list, as shown in Table 23.

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. The current status is shown in Figure 43.

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RESEARCH ACTIVITIES

SP1 BIOMASS SUPPLY AND RESIDUE UTILIZATION

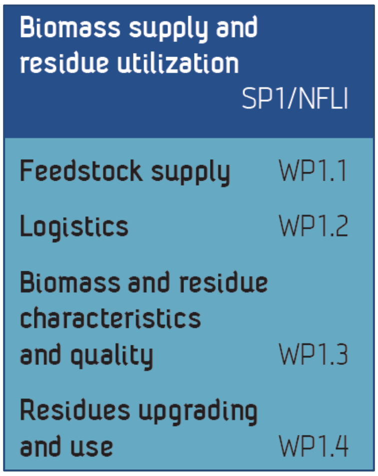

Figure 7: WBS of SP1.

Simen Gjølsjø
Leader of Biomass Supply and Residue Utilization
(photo: Lars Sandved Dalen)

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

We develop bio-economic optimization methods and models handling the linkage between biological production, silvicultural management, economic behavior, sustainability criteria and biomass supply, and use these in decision-support systems analyzing present and future potentially available biomass resources for energy production. Biomass qualities also greatly vary related to plant specific characteristics, growing site characteristics, as well as processing and storage characteristics. The amount and composition of residues after conversion to energy rely on biomass quality (homogeneity), as well as the technology applied. Residues may be upgraded or refined, and used further in industrial processes, deposited (road-fillings) or recycled back as fertilizer in plant production processes.

WP1.1 – Feedstock supply

The role of WP1.1 may be divided into two main parts:

- To develop new methods and models that can be used in inventories for assessing forest biomass and to use these in the search for potentially available biomass resources for energy production at different institutional and geographical levels.
- To develop bio-economic optimization methods and models handling the linkage between biological production, silvicultural management, economic behavior, sustainability criteria and biomass supply and to use these in decision-support systems analyzing present and future potentially available biomass resources energy production.

Biomass expansion factors

A study[1] was carried out to develop biomass expansion factors (BEFs; ratio of stem volume to biomass), which convert stem volume to whole tree biomass for Norwegian forest conditions. Stand-level models for BEF were developed for the following tree components; stem, bark, living branches, dead branches, foliage, below-ground for bioenergy use, total below-ground and total biomass. Volume per hectare, and site index were chosen as independent variables. The models in general performed well and can be applied mostly all over Norway. However, there are some indications of poorer performance in low-productive stands (site index class 6), on the west-coast, in the southeast region at elevation higher than 750 meters above sea level.

Present biomass resources in Norway

We carried out a national assessment of woody biomass in Norway including trees outside the forest[2]. The estimated biomass in productive forest is approximately 780 million tons dry matter (d.m.), which corresponds to 90 % of the biomass in the inventoried land-use classes. In productive forests, the reduction of harvestable biomass due to environmental protection is approximately 21% in mature forest. Trees outside the forest were found to be small resource containing less than 1.5% of the total woody biomass. Based on rough assumptions, it can be realized that the annual potential national woody biomass contribution from these land-use classes is less than 2 Twh. We also developed cost-supply curves of potential national supply of harvest residues, and the analyses showed that energy potential can reach an annual production of around 5-6 TWh at a cost of 40 EUR/ton d.m. biomass based on the present timber harvesting activities in Norway. In order to imagine a scenario where forest residues and trees outside the forest produce 14 TWh, a larger proportion of the stems would have to be included in the harvest residues and the harvest would have to be between 30 and 50% higher than today.

A bio-economic model appraisal – harvest residue potential in Norway

The Government has proposed to increase the annual use of bioenergy by 14 TWh by year 2020. A large part of the increase needs to be based on residues from conventional timber harvesting. Therefore, we have provided cost-supply curves[3] at national and regional levels from residue harvesting. A modeling approach that includes a detailed description of the Norwegian forest area based on NFI sample plots has been used and combined with different scenarios projecting possible harvest paths. This includes sufficiently detailed information to estimate necessary biomass fractions and to calculate costs of harvest residues extraction. With a maximum estimated annual energy production of 5.3 TWh from harvest residues based on the present harvest level, there is still a large gap to bridge and reach the official target. In principle, there are two ways to bridge the gap; the general timber harvesting level can be increased and thus, the corresponding residue supply, or the use of round wood for energy purposes can be increased at the expense of pulpwood. Scenarios where the timber production levels in the long run are increased give estimated annual energy production levels varying from 6-9 TWh. Given the present market conditions for the products involved and/or the general policy framework for bioenergy production in Norway, it is not very likely that the gap will be bridged in a short term perspective. In the long run, there are more options, since both market and political conditions, as well as forest management, may be changed towards better conditions for bioenergy production.

[1] Viken, K.O, Astrup, R. and Eid, T. *Biomass expansion factors (BEFs) for pine (Pinus spp.), spruce (Picea spp.), birch (Betula spp.) and broadleaved dominated stands in Norway*. Submitted to Silva Fennica in 2012

[2] Astrup, R., Eid, T., Antón-Fernández, C., Løken, Ø., Søgaard, G. & Eriksen, R. 2012. *An assessment of woody biomass in Norway: Total availability and harvest residue cost-supply curves*. Submitted to Biomass and Bioenergy in 2012

[3] Bergseng, E., Eid, T. & Løken, Ø. & Astrup, R. 2012. *Harvest residue potential in Norway – a bio-economic model appraisal*. Submitted Scandinavian Journal of Forest Research in 2012

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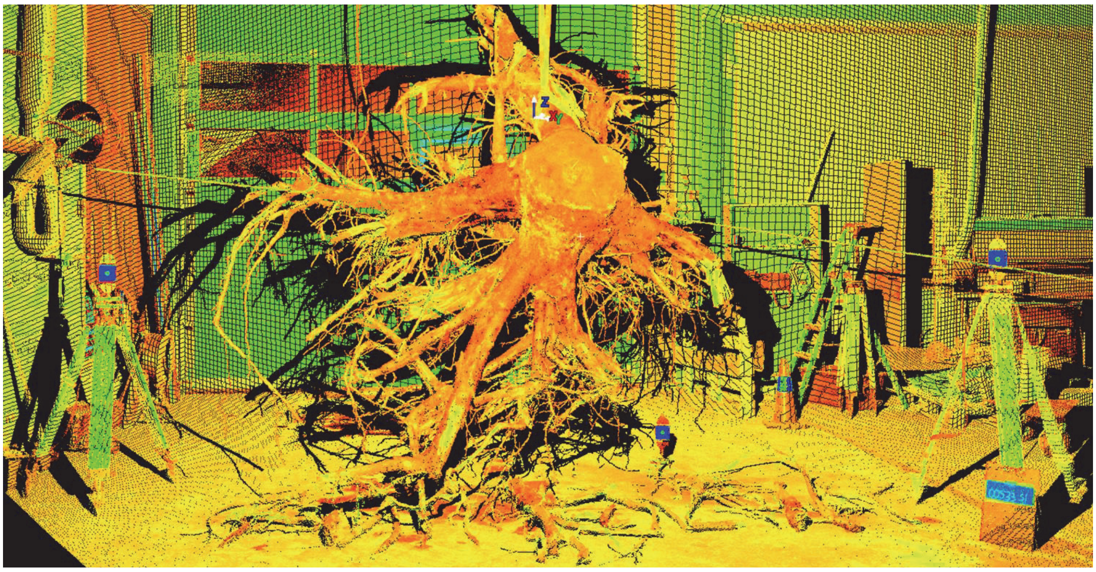

Figure 8: Example of terrestrial LiDAR scan of a tree stump. This is made to feed-in the bio-economic model, by developing volume models based on cut diameters. A tree stump is the portion of the trunk with the roots still in the ground, remaining after the tree has been cut or felled. (photo: Aaron Smith)

Adjacency constraints in forest planning – new methods based on simulated annealing

Spatial considerations and related adjacency constraints are essential in long-term forest planning related to conventional timber production and biomass production for energy purposes. Adjacency constraints are typically imposed in order to preserve wildlife habitats or enhance scenic beauty. Norway has long traditions in developing and applying decision support systems for long-term forest planning. However, no presently working decision support system has incorporated yet any functionality dealing with adjacency constraints. Internationally, simulated annealing (SA) has already been successfully applied when addressing such constraints. The objective of this research[4] was to assess the performance of three new methods that we have developed and to compare them to the conventional method used for SA. In general, the new methods provided better solutions compared to the conventional method. Though the new methods require slightly more computational time, the results are promising and the best of the new methods is very likely to be implemented in existing decision support system in Norway.

Expectations for the next years

Decision-support systems

The work will go further on, focusing especially on the following main tasks:

- Operationalize biomass production models for cost estimate in existing systems for decision-support. The work will be based on input from WP1.2.
- Endogenize forest biomass for energy as a product in decision-support models to optimize forest production both temporally and spatially in the future.
- Incorporate and operationalize methods dealing with adjacency constraints in existing systems for decision-support. Analyze impact of such constraints on biomass production potentials.

[4] Borges, P. Bergseng, E. & Eid, T. *Adjacency constraints in forestry – an applying simulated annealing using different methods for the neighbourhood exploration*. Submitted to European Journal of Operational Research in 2012

Biomass mapping

A PhD-project on evaluation and development of allometric biomass equations will continue. The work related to biomass maps will also keep on. An initial feasibility study using photogrammetry and NFI plots as ground-truth is done. A work related to sampling methods utilizing terrestrial laser scanning for biomass estimation has started and will continue. The aim is to provide a biomass estimate of individual trees and stands utilizing a terrestrial laser scanning system.

Value chains

WP1.1 deals with estimation, availability and production of tree biomass resources. Together with WP1.2, we cover the value chain from "stump to roadside and power plant". We have sample plot data and biomass maps covering entirely Norway, which can be used as input in sustainability analyses related to the ecology, as well as the economy of promising bioenergy production value chains. Therefore, we expect to be an important data provider and to take part in different analyses related to this. Examples of problems to solve could be the "Optimal location of biomass-based power plants related to forest resources" or the "Cost and supply curves for specific power plant locations".

WP1.2 – Logistics

The role of WP1.2 is to provide the technical and operational-economic framework for the supply of biomass from stump to plant. This includes documenting all machinery available or in use in the Scandinavian bioenergy supply setting and putting together technically workable supply chains. The productivity, cost, and economics of the application of each of these machines and systems is calculated on the basis of field trials (time and motion studies), and evaluated against varying forest parameters in a simulated environment. The latter uses inputs from WP1.1 on forest metrics and allows for innovative new productions systems to be conceptualized and tested against conventional methods. Through field trials, WP1.2 also plays an important role in collecting forest fuel samples from varying origins (GROT, bundles, whole trees, steep terrain) and supplying these into WP1.3 for further analysis.

Overview of biomass production and delivery systems

The completion of a number of reports marked a high level of activity in WP1.2 during 2012. A technical survey report[5] documented the predominant production systems in Norway and neighboring countries, their areas of application and their expected productivities. The report, which includes an overview of equipment and machinery suppliers in Norway, covers everything from stump harvesting, early thinning, integrated harvesting and the collection of harvesting residues. Processing options at each link in the chain are also discussed, as well as the guideline on the planning and management of biomass supply chains.

Economic evaluation of accumulating felling and harvesting heads

A study, finalized in 2012 as a peer-reviewed paper[6], showed the importance of correct selection of felling/harvesting heads in biomass operations, depending primarily on tree-size distribution and whether or not the machine is intended for use in conventional logging operations. Results show that the requirement of more expensive harvesting heads is mostly due to the

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[5] Talbot, B. *Overview of biomass production and delivery systems*. Restricted report, 2012

[6] Belbo, H. *Economic evaluation of accumulating felling and harvesting heads*. Submitted for review in 2012

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increased flexibility of utilization (from biomass to conventional sawlog operations), as well as the benefit of having feed-rollers. This leads to better load compaction, rough debranching, and cross-cutting of the bundled trees.

Figure 9: John Deere bundler in action. (photo: Leif Kjøstelsen)

Bundling of vegetation from roadside maintenance

The productivity and economics of bundling and transport of small whole trees from roadside vegetation has been studied[7], since it represents a potentially vast resource. There were three comparative treatments: bundling of freshly cut trees, bundling of summer dried trees and bundling of whole trees together with harvesting residues. Bundles of roughly 200 kg d.m. were produced at a cost ranging between 49-81 NOK/MWh. The productivity of the bundler ranged between 4.75-7.3 tons d.m. per effective work hour. Bundles were transported to a plant 50 km away for another 41-46 NOK/MWh.

Quantity and quality of biomass from steep terrain operations

Biomass from harvesting in steep terrain represents a high potential, since it is extracted to roadside at no extra cost compared to conventional operations. The potential for logging residues in Western Norway is estimated at 3.5 million tons d.m. (Løken 2012)[8]. Results of a study[9] showed that the biomass volume of logging residues (GROT) ranged between 25-28% of the stem wood volume and roughly 3 m^3 could be produced per hour.

Economic Sustainability of Biomass Supply

The economic sustainability of actors in the supply chain, seen from a contractor perspective, has been investigated in CenBio and reported[10] for the IEA Task 43. Economic sustainability is all about long-term stability and balance. When production activities yield higher benefits than costs over their complete life cycle, taking into account all environmental, social, and economic factors, then the activities are considered economically sustainable[11]. While operating and pursuing profits

[7] Belbo, H. & Kjøstelsen, L. *Bunting av vegkantvirke: Produktivitet og økonomi*. Report from NFLI, 2012

[8] Løken, Ø, *Den totale biomassen av trær i Norge*. Ås. Report from NFLI, 2012

[9] Nordhagen, E. *Recovery of logging residues from final harvest in steep terrain in Nordland*. Report from NFLI, 2012

[10] Ikonen, T. (ed.) et al.(Talbot). *Economic Sustainability of Biomass Supply*. IEA TASK 43 report 2012

[11] Hardisty, P. E. *Environmental and economics sustainability.* CRC Press, 2012

on the short-term, companies have to ensure that the business operations do not create environmental concerns, since those could tip local and global ecologies in the long-term[12]. Operating in a short, quarter-based timescale, companies cannot guarantee correct decision-making and economically sustainable operations, thereby jeopardizing long-term profitability. Strategic planning in 2-5 years periods and stability in business operations are required for creating local welfare and prosperity.

Figure 10: Tree harvesting operation in progress in steep terrain. (photos: Eirik Nordhagen)

Good Practice Guidelines – Biomass Production Studies

In the context of COST FP0902, good practice guidelines were investigated and published[13] for designing and carrying out field studies where the production of biomass for energy is the primary goal. The guidelines include a history of performance measuring, cover ethics and safety issues related to measuring individuals or systems, discuss research design and trial layout, methods and technologies for data capture (including fuel measurement), and include a short chapter on data processing and results interpretation.

Selecting between wood fuel supply chains on the basis of economic performance and robustness – evaluation approach and decision criterions

Ten different technical supply systems were analyzed in a simulated environment, based on existing production functions. The results[14] showed that there is about 20% difference between the cheapest path and the most expensive one, and that each supply chain can justify its existence depending on regional transport distances and volumes available at each site. The challenge here is to determine the predominant values for individual supply chains. The plan is to further develop this report into a peer-reviewed journal publication.

[12] Anon, *Ecology; All forms of life in relation to environment.* Read book design, 2011

[13] Magagnotti, N. & Spinelli, R. (eds.) et al. (Talbot) 2012. *Good Practice Guidelines for Biomass Production Studies.* ISBN 978-88-901660-4-4. 52pp.

[14] Belbo, H., Talbot, B. & Kjøstelsen, L. *Skogflisproduksjon fra heltrevirke: Systemanalyse.* Report from NFLI, 2012

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International Cooperation

On the international scene, WP1.2 participants have played an active role in COST FP0902 (Development and harmonization of new operational research and assessment procedures for sustainable forest biomass supply). There, the results of a CenBio study were delivered in a keynote presentation at the annual meeting in Portugal (18-20 September 2012). We also contributed to a 'best practice guideline' on biomass productivity studies for this COST group.

WP1.2 participants have played a central role (including NTL) in IEA Task 43 (Biomass feedstock for energy markets) and have participated in IEA meetings in South Carolina (USA), Lisbon (Portugal) and Vienna (Austria) during this period. Participants contributed to one of the main outputs of the Task for the present triennium – an IEA report on "economically sustainable supply chains". Participation in this IEA Task is almost totally funded by CenBio WP1.2.

Cross-funding of WP1.2 and activities in the Nordic Energy Fund sponsored ENERWOODS project, (which includes Norway, Sweden, Finland, Latvia and Estonia), have led to significant cooperation with some of the leading institutes in the Nordic setting. The synergy from tasks defined in that project has allowed for comparative studies and experiences to be shared across borders.

The Nordic Council of Ministers (SNS) sponsored Operations Systems Centre of Advanced Research (OSCAR) provides a central networking platform in the Nordic Baltic countries, where biomass for bioenergy has been one of the priority areas. All participants are active in OSCAR, including representation in the coordination committee. Through this network, WP1.2 has benefitted by partnering with Skogforsk in Sweden in a special cooperation developing supply chain modules in a common supply chain simulation effort.

WP1.3 – Biomass and residue characteristics and quality

The role of WP1.3 is to study in details the characteristics of Norwegian biomass. Variations in tree types, location and different parts of trees are studied in terms of combustion characteristics and ash content. Mixtures of different feedstock, in order to produce an optimized fuel with reduced emissions, have been also investigated. Theses fuel optimizations also prolong the lifetime of the combustion plant, since they produce flue gas with reduced corrosive compounds. Another advantage for fuel mixing is to use low grade biomass, since it is cheap and makes energy conversion more competitive with other known sustainable fuel sources.

Fuel characterization of spruce grown in different conditions

The main work in 2012 concentrated on studying fuel characteristics of 8 samples of spruce harvested at different locations in Norway and to qualify their quality. Both clean woodchips, and tops and branches were characterized.

Testing of torrefied fuels in small-scale units

Two of the samples mentioned above were chosen as fuels for the study of particle emissions from a small scale pellets combustor. This work is a joint collaboration with WP2.5 (KMB STOP: Torrefaction). The focus of the combustion study has been set on looking in detail at the flue gas emissions at different combustor loads. In particular, great attention was given to study the effect of torrefaction on the fly ash particle size distribution and composition. The experimental campaign has ended recently (October 2012) and the data has been treated.

The dust emissions that were collected on Teflon filter after removing particles larger than 1 µm through the use of a DLPI (Dekati Low-Pressure Impactor) are shown in Figure 11. Figure 12 shows the metal composition of the same Teflon filter.

A peer-reviewed journal publication based on this work has been written in 2012 and will be submitted to the level 2 journal Energy & Fuels in 2013.

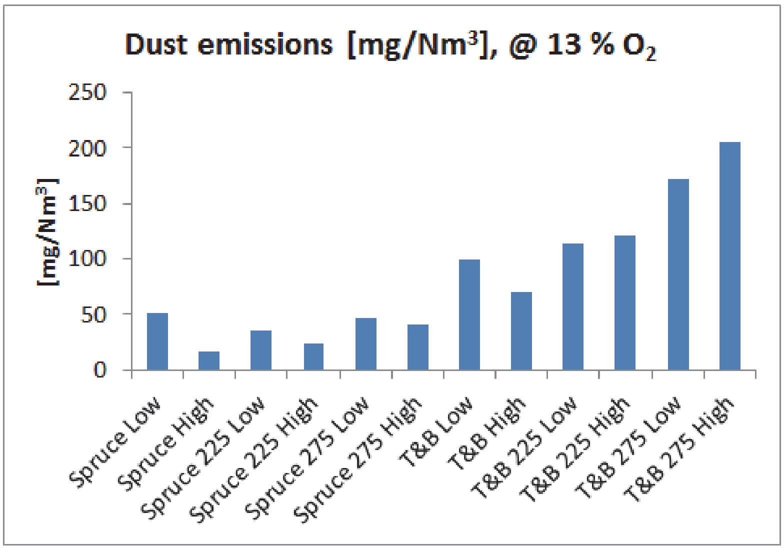

Figure 11: Dust emissions of particles below 1-µm diameter in mg/Nm³ flue gas corrected to 13 % O_2.

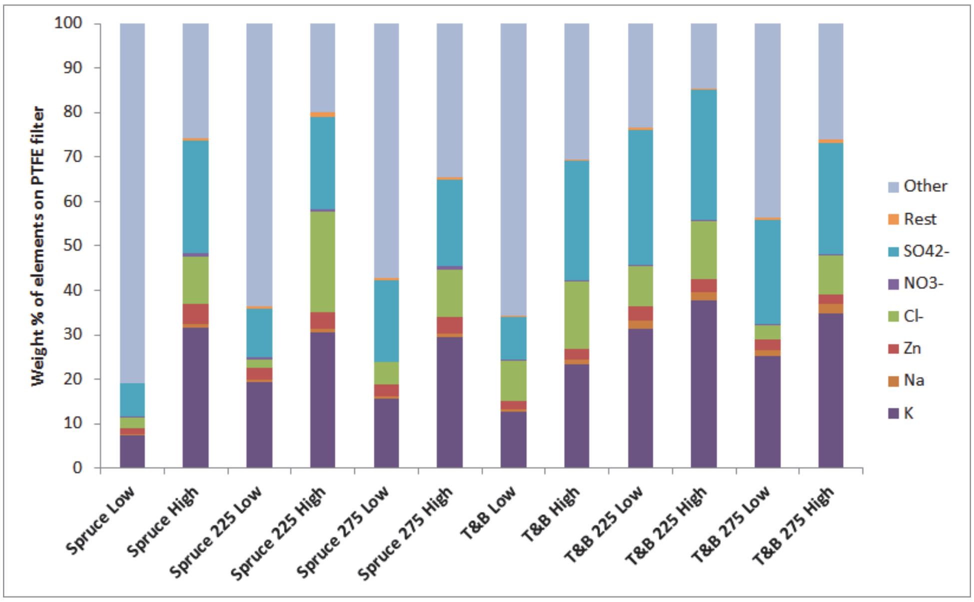

Figure 12: Element composition of metals for particles below 1 µm collected on the Teflon filter.

Size classification of wood chips

European Standards defines the fuel quality classes and specifications for solid biofuels. The EN standards are tools for international trade of solid biofuels. NFLI has analyzed 120 samples of wood chips for particle size distribution according to EN 15149-1. Figure 13 shows the mean cumulative particle size distribution for logging residue, stem wood and whole tree.

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Smaller grate fired boilers need low amount of fines (< 3.15 mm) usually 6 – 8 weight-%. Long sticks (> 120 mm) can cause problems in small-scale boilers. Large grate fired boilers (> 1 MW) can usually handle fine fractions until 25 w-%. Fluidized bed boilers can tolerate up to 25 – 30 w-% of fine particles (usually less than 5 mm).

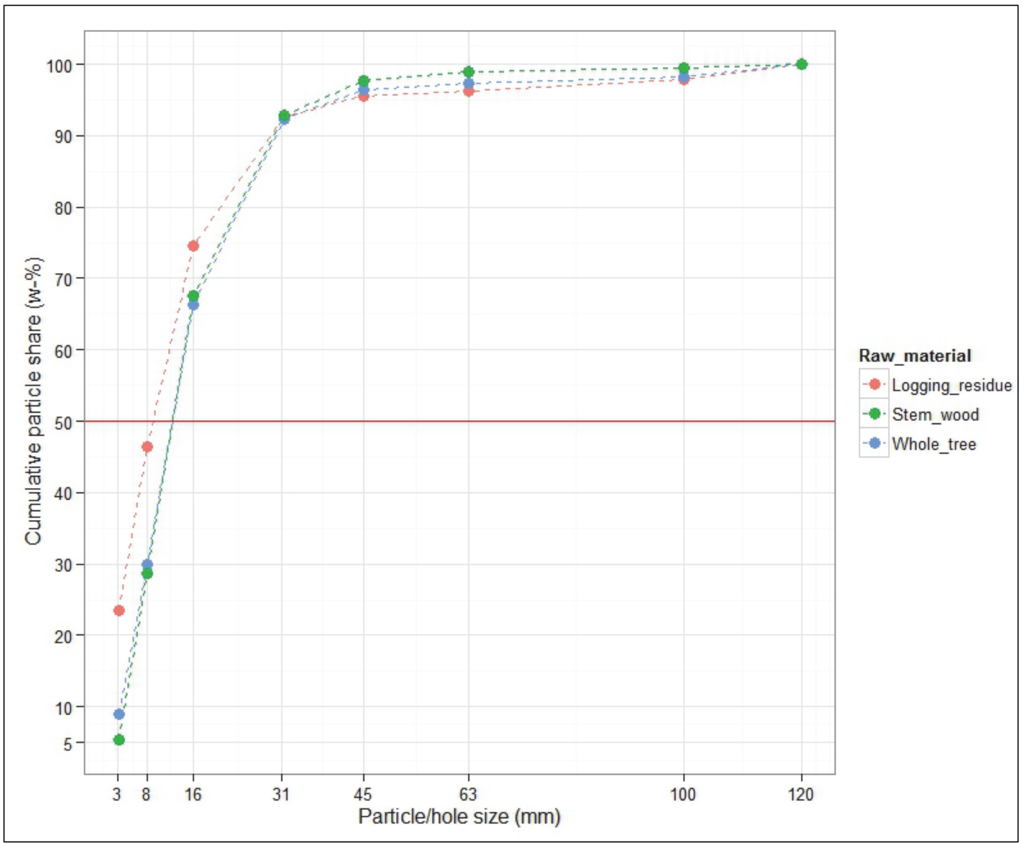

Figure 13: Cumulative particle size distribution (weight-%) of different raw material.

Expectations for the next years

The work on fuel characterization of different fuels will continue in the coming years. Concerning 2013, it has already been planned to look into trees grown in steep terrains and near the coast line. Such trees have the tendency to have an ash content that differs, both in quantity and chemical composition compared to trees grown on flat terrain. This is due to exposure to oceanic salt (HCl, NaCl), which can be taken by the tree during growth and might lead to higher concentration of these trace elements. In addition, due to different harvesting methods (trees are pulled by a cable system), the collected trees usually contain higher amounts gravel, which will contribute to an increased ash content. In cooperation with WP1.2, trees with aforementioned properties will be collected and the ash content analyzed. Combustion experiments under controlled conditions will be performed to check whether there is a substantial difference in the ash compared to normal wood. The experimental work will focus on the performance of advanced measurements of the particle emission, which is a relevant indicator for corrosion. The experimental work on combustion will be performed in collaboration with the CenBio WP2.1 (combustion).

As a result of redefining the CenBio strategy and the increased focus on work towards value chain assessment, part of the work load of WP1.3 will be reserved for this specific task. Concerning 2013, most of the work in this task will focus on establishing methodology for an optimum cooperation between the different CenBio partners. The result should end up in clarifying the type of data that the different partners will need to collect in order provide a sound foundation for the different value chains.

In a 3 years perspective, WP1.3 will also contribute in the development of these value chains by providing data on the influence of different feedstock characteristics on the value chain relatively to changes in the plant efficiency, and increased costs from higher complexity of the gas cleaning system.

The classification of wood chips is relatively complex, and in ISO, there is a new draft for standards for wood chips and hog fuel. NLFI is a member of working group 2 in ISO/TC 238 and will continue to analyze wood chips according to international standards on solid biofuels.

WP1.4 – Residue upgrading and use

Utilization of wood ash and anaerobic digestates has been given priority, and the research on ash utilization has so far been the major activity in WP1.4. Our approach has been a combination of different waste streams containing various plant nutrients, in order to produce recycled NPK fertilizer. The first results were published[15] in 2011 and show the possibility of combining bottom wood ash (BWA) and meat and bone meal (MBM) as NPK fertilizer. Another journal paper on the same topic was published in 2012[16].

In the combined fertilizer products we have investigated so far, the NPK balance has not been optimal according to the plants' demand. This is partly due to better effect of P, both from BWA and MBM, than expected from previous investigations, and decreased N effect by increasing amounts of organic N rich waste materials as fertilizers. In further studies, combinations with mineral N and K will be introduced to the concept of producing recycled NPK fertilizer. Since the farmers need NPK fertilizers with reliable effects, recycled fertilizer products need to be improved in order to substitute mineral NPK fertilizers.

However, the research has led to the identification of new approaches for application of wood ash. Since the experiments have shown that ash, in addition to liming effect, also contains plant available phosphorus (P), potassium (K) and trace element, a license agreement of a soil mixture for urban greening using ash for pH optimization and source for P and K, has been signed and represents an innovation of CenBio WP1.4 (see Table 5).

It has also been found that ash has other interesting properties and can be used to prevent germination of weeds in sand mixtures. A recipe for a product has been licensed to an industry partner in 2012. However, the properties of the ash used for such purpose are very strict, since the ash influences both the chemical and physical properties of the mixture, as well as the visual appearance.

[15] Insam, H., Knapp, B. A. *Recycling of Biomass Ashes*, Springer Verlag 2011

[16] Brod, E., Haraldsen, T.K. & Breland, T.A. *Fertilization effects of organic waste resources and bottom wood ash: results from a pot experiment.* Agriculture and Food Science 21(4): 332-347 (2012)

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Figure 14: Large differences between treatments in pot experiments with ash and N-rich waste products. Source *[16]*

Since May 2012, Eva Brod has been employed as a Ph.D. student at Bioforsk Soil and Environment. Her Ph.D. work will partly be related to WP1.4 in CenBio, the RCN project "*Innovative utilization of wood ash*", and the RCN project "*Sustained and increased organic cereal production by improved nutrient supply and pest control*". The main activity in WP1.4 for the coming years will be the studies which are part of the Ph.D. work for Eva Brod.

SP2 CONVERSION MECHANISMS

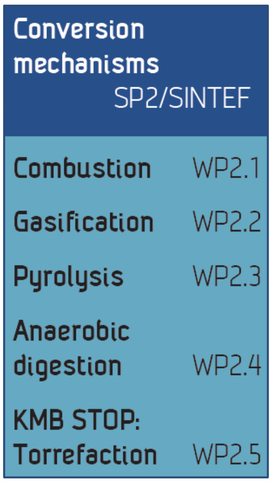

Figure 15: WBS of SP2.

Michaël Becidan
Leader of Conversion Mechanisms
(photo: Gry Karin Stimo)

SP2 encompasses combustion, gasification, pyrolysis, anaerobic digestion and torrefaction (as a pre-treatment method). The work is especially focused on challenging resources, which are essential to increase the bioenergy production in Norway. Challenging biomass includes forest and agricultural residues, food waste and sewage sludge, which are all largely unexploited in Norway.

The work on combustion addresses the operational challenges of running Biomass-to-Energy (BtE) plants, such as developing additives against corrosion, slagging and fouling. The extensive testing and characterization of novel, innovative additives to fight ash-related challenges, namely zeolites, and evaluating their efficiencies when combusting fuels such as barley husk and wheat straw, is a remarkable achievement of CenBio.

Pyrolysis activities focus on enabling energy efficient biocarbon (bio charcoal) production. This is a novel fuel with potentially higher energy density and better homogeneity than most biomass fuels. It offers a unique opportunity for combustion stability and emission control, and could also be used as a peak load fuel, instead of fossil fuels, to ensure 100% renewability in BtE plants. Biocarbon is also easily crushed. Increasing the pressure in the process has proven interesting – promoting tars condensation. This work is carried out in close collaboration with the internationally leading expert in the field, Professor Michael Jerry Antal Jr., from the University of Hawaii.

The current (political) goal is to treat 30% of the manure by anaerobic digestion within 2020. Most biogas processes produce far less methane than expected from theoretical calculations. In CenBio, there are activities to broaden the spectrum of feedstock, to improve the digestibility and to improve the quality of digestate to produce fertilizers. In January 2012, a new Biogas lab opened at UMB. This contributed to new collaborations with Swedish and Danish research groups.

The fuel pre-treatment technology torrefaction is also an integral part of CenBio through the RCN KMB STOP project. This is a mild pyrolysis process (200-300 °C), leading to increased energy density, enhanced grindability, better homogeneity and improved logistics. A novel, in-house designed, innovative torrefaction reactor has been built in the thermal laboratories at SINTEF Energy Research (see Figure 25). Experimental investigations of the properties of torrefied fuels are underway.

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WP2.1 Combustion

CenBio aims at maximizing NOx reduction by primary measures

Staged combustion is the most effective primary NOx emission reduction measure. By staged air combustion, about 90% NOx reduction was achieved in a grate fired multi-fuel reactor in an earlier experimental campaign in CenBio.

Figure 16 shows the grate fired multi-fuel reactor at the Trondheim Bioenergy Laboratory and the NOx emissions as a function of primary excess air ratio. The optimum primary excess air ratio can easily be pinpointed in the figure.

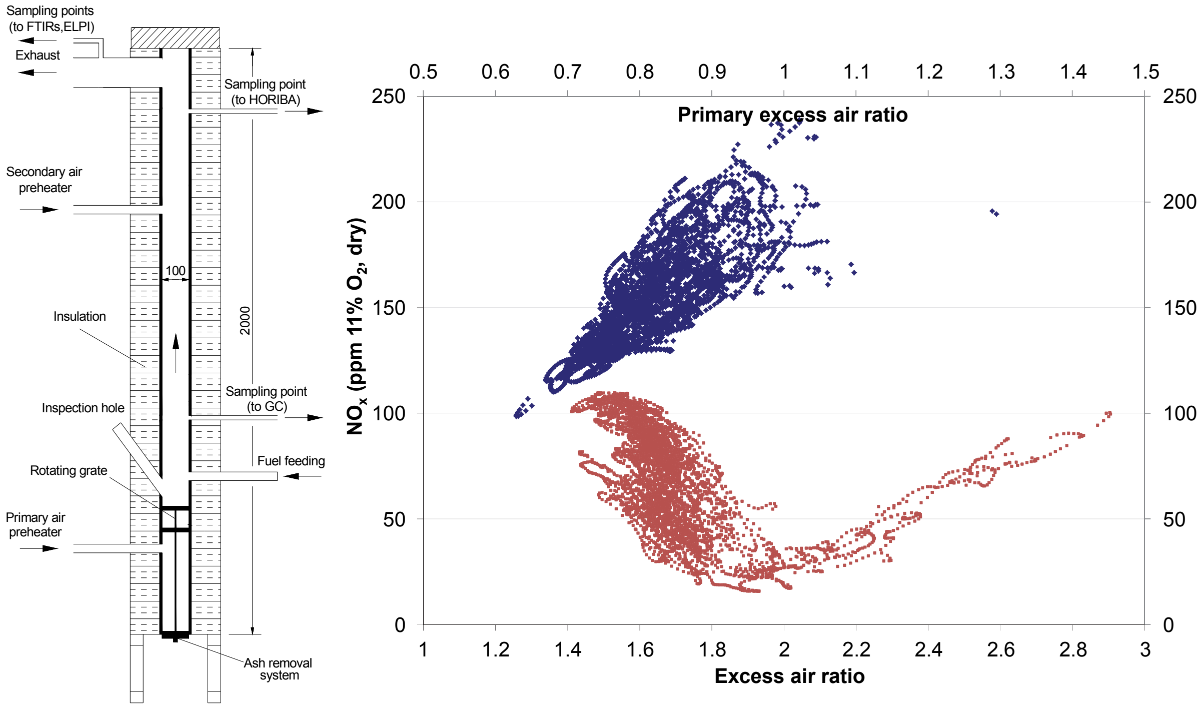


Figure 16: The multi-fuel reactor and the NOx emissions as a function of primary excess air ratio for staged combustion (red) and non-staged combustion (blue).

However, modeling of such processes becomes more complex and reduced (simplified) kinetic mechanisms may not be able to model adequately well the combustion process.

In this activity, previously developed reduced kinetics mechanisms[17] are applied to an ideal flow reactor and their ability to reproduce experimental data[18] is tested. In addition, the full mechanism (from where the reduced kinetics is derived) is tested against the experimental data and its quality is compared to the performance of earlier full mechanisms[19]. The weaknesses of the reduced kinetics with respect to modeling condition ranges and the representation of the kinetics of the full mechanism have been identified. The correctness of the reduced kinetics, expressed as valid modeling condition ranges, is identified.

[17] Houshfar E., Skreiberg Ø., Glarborg P., Løvås T. *Reduced chemical kinetics mechanisms for NOx emission prediction in biomass combustion. International Journal of Chemical Kinetics.* DOI: 10.1002/kin.20716. (2012)

[18] Hasegawa T., Sato M. *Study of ammonia removal from coal-gasified fuel.* Combustion and Flame, Vol, 114, pp. 246–258 (1998)

[19] Skreiberg Ø., Kilpinen P., Glarborg P. *Ammonia chemistry below 1400 K under fuel-rich conditions in a flow reactor.* Combustion and Flame, Vol. 136, pp. 501-518 (2004)

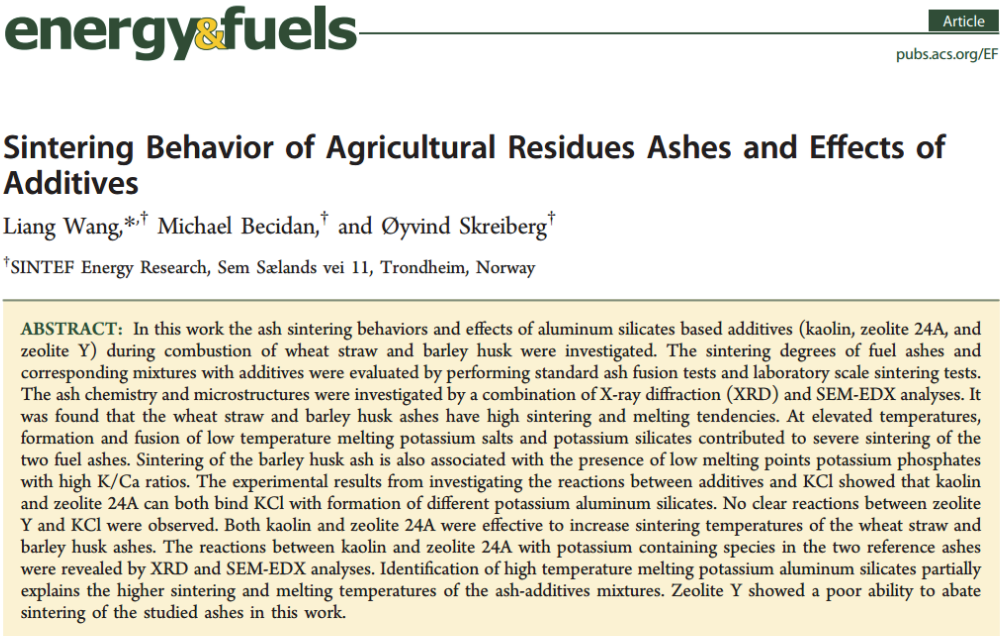
The next step is to apply the reduced kinetics in Computational Fluid Dynamics (CFD) modeling, to reproduce experimental data from the grate fired multi-fuel reactor in the bioenergy laboratory in Trondheim for staged combustion conditions. This is a co-operation with WP3.4 (Emissions). In this work, a refined reduced mechanism may be developed if needed, optimized for the operating window of the multi-fuel reactor.

The ultimate aim is to adequately model the staged air combustion process to be able to identify optimum operation conditions for maximum NOx reduction. The most important parameters are the primary excess air ratio and the total excess air ratio, while the temperature is less important in the typical temperature range in a grate fired reactor.

Additives and fuel mixes for reduced corrosion and fouling - Experimental study

Utilization of additives is a promising and practical way to abate ash-related issues during thermal treatment of biomass. Based on this, intensive and innovative experiment work has and will be done at SINTEF Energy Research, searching for and testing new and financially attractive additives.

This task includes two phases. The experimental work done in phase I has been published[20] in a level 2 international journal. The abstract is shown in Figure 17. Based on promising results obtained from phase I, more experimental work has been carried out in 2012. This work focuses on reaction mechanisms of additives with problematic ash forming matters at elevated temperatures. Figure 18 shows the capacity of three additives to capture corrosive KCl (g) at increasing temperatures. The residues will be analyzed with a combination of advanced analytical methods, namely ICP-OES, SEM-EDS and XRD. Key factors influencing reactions between additives and the K-containing species will also be investigated. In addition, the additives may also be premixed with biomass ashes and burned under conditions simulating those in the typical biomass combustion boiler. The aim is to study the effect of additive addition on the chemical composition and characteristics of the biomass ashes at high temperatures.


energy&fuels Article pubs.acs.org/EF

Sintering Behavior of Agricultural Residues Ashes and Effects of Additives

Liang Wang,*,† Michael Becidan,† and Øyvind Skreiberg†

†SINTEF Energy Research, Sem Sælands vei 11, Trondheim, Norway

ABSTRACT: In this work the ash sintering behaviors and effects of aluminum silicates based additives (kaolin, zeolite 24A, and zeolite Y) during combustion of wheat straw and barley husk were investigated. The sintering degrees of fuel ashes and corresponding mixtures with additives were evaluated by performing standard ash fusion tests and laboratory scale sintering tests. The ash chemistry and microstructures were investigated by a combination of X-ray diffraction (XRD) and SEM-EDX analyses. It was found that the wheat straw and barley husk ashes have high sintering and melting tendencies. At elevated temperatures, formation and fusion of low temperature melting potassium salts and potassium silicates contributed to severe sintering of the two fuel ashes. Sintering of the barley husk ash is also associated with the presence of low melting points potassium phosphates with high K/Ca ratios. The experimental results from investigating the reactions between additives and KCl showed that kaolin and zeolite 24A can both bind KCl with formation of different potassium aluminum silicates. No clear reactions between zeolite Y and KCl were observed. Both kaolin and zeolite 24A were effective to increase sintering temperatures of the wheat straw and barley husk ashes. The reactions between kaolin and zeolite 24A with potassium containing species in the two reference ashes were revealed by XRD and SEM-EDX analyses. Identification of high temperature melting potassium aluminum silicates partially explains the higher sintering and melting temperatures of the ash-additives mixtures. Zeolite Y showed a poor ability to abate sintering of the studied ashes in this work.

Figure 17: Abstract from published paper[20] on experimental work on additives and fuel mixes for corrosion and fouling reduction (Phase I).

[20] Wang L., Becidan M., Skreiberg Ø. *Sintering of Agricultural Residues Ashes and Effects of Additives.* Energy & Fuels, 26 (9), pp. 5917–5929 (2012)

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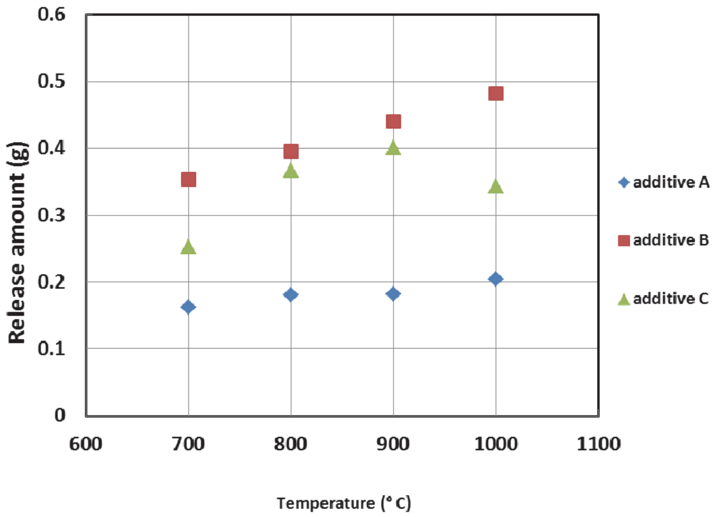

Figure 18: Preliminary results from additive related experimental work (Phase II).

In another work[21], the effects of three potential additives (sewage sludge, marble sludge and clay sludge) on two challenging biomass ashes (wheat straw and wood wastes ashes) sintering tendencies were investigated. The sintering abating abilities of the additives were evaluated by performing standard ash fusion and lab-scale sintering tests on mixtures of biomass ashes and additives. The possible mechanisms for the anti-sintering effects of the additives were examined by a combination of XRD and SEM-EDX analyses. It was found that marble sludge is the most effective additive. The dilution effect of marble sludge on biomass ashes is considered as the main reason for the decreased ash sintering degree. In addition, together with XRD results, SEM-EDX analysis revealed that calcium (Ca) from marble sludge may also result in formation of high-melting-temperature potassium-calcium-silicates and potassium-calcium-phosphates with low K/Ca ratios. Sewage sludge showed abilities to reduce the sintering degrees of both biomass ashes via chemical reactions and dilution effects. The influence of additives on fusion temperatures and sintering behaviors of two biomass ashes are shown in Figure 19.

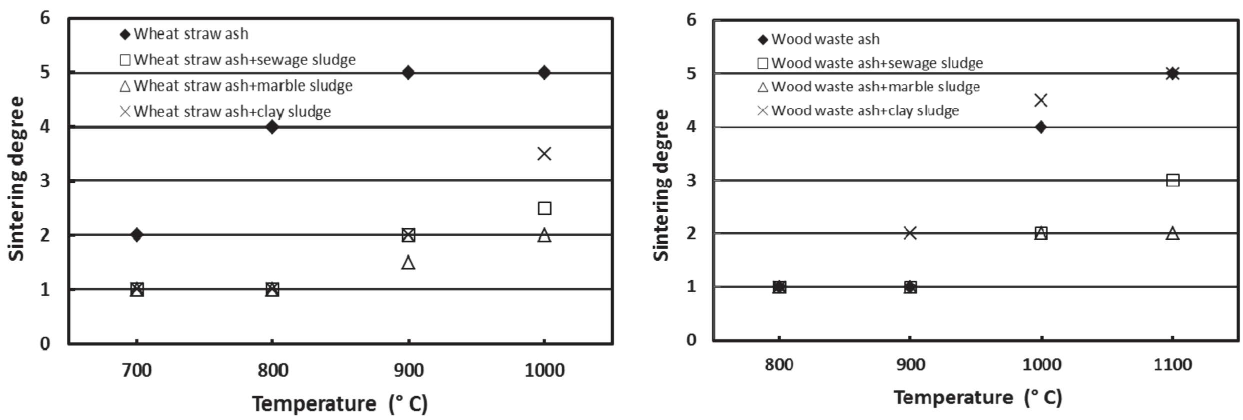

Figure 19: Sintering behaviors of biomass ashes and effects of additives.

[21] Wang L., Skjevrak G., Hustad J. E., Skreiberg Ø. *Influence of additives from wastes on biomass ash sintering tendency*. Journal article submitted to Energy & Fuels in August 2012

WP2.2 Gasification

In 2012, the work focused on thermodynamic equilibrium modeling for syngas formation. The first important step of this activity was the establishment of a custom-made database containing all the possible (gas phase + solid carbon) products during gasification of waste and biomass.

A correct database is central as the exclusion or inclusion of a given compound could have dramatic consequences on the quality of the calculation results. The database was built up using SINTEF Energy Research expertise, current international literature and extensive discussions with a CenBio industrial partner, namely Energos. The most important considerations were:

- Focus was put on the main C-H-O compounds.
- The database is to be used for high temperature calculations, i.e. not below ca. 600°C.
- The ash compounds are not considered (so-called "black box" approach).
- Cl and S were not included.
- Only N_2 was considered for nitrogen species as especially NOx chemistry is kinetically controlled. Nitrogen is therefore considered as an inert element.
- Tars are of special interest but are constituted of a large number of different species, mainly ring (poly) aromatic hydrocarbons. To approach this complexity in the calculations, a selection of such aromatic hydrocarbons was included as (the most) representative tar species, i.e. C_6H_6 (benzene), C_6H_6O (phenol), toluene (C_7H_8), xylene (C_8H_{10}), naphtalene ($C_{10}H_8$), styrene (C_8H_8), biphenyl $(C_6H_5)_2$, acenaphtalene ($C_{12}H_{10}$).
- Several PAH (proposed by SINTEF Energy research and/or Energos) could not be included as no thermodynamic data were available in the commercial databases. This includes: acenaphtylene ($C_{12}H_8$), chrysene, anthracene ($C_{14}H_{10}$) and benzo-a-anthracene ($C_{18}H_{12}$).
- Other compounds not included do to a lack of thermodynamic data: C_3H_5, HCCO, HCCOH and CH_2CHO.

Tests calculations were carried out in late 2012. Energos and SINTEF-ER are now (2013) working on a common conference article to be submitted to the 14th International Waste Management and Landfill Symposium in Sardinia (Italy), 30 September to 4 October 2013.

WP2.3 Pyrolysis

Biocarbon production is a promising way for sustainable energy generation and combating global climate change. Development of the biocarbon production process is required to increase charcoal yields from biomass feedstocks and the fixed carbon contents of the produced charcoals. Current experimental results show that both higher charcoal yields and fixed carbon contents can be achieved by carbonizing biomass materials (corncob, oak wood and sweet gum) under elevated pressure and/or using feedstock with larger particle sizes, as shown in Figure 20.

These parameters extend the residence time of tarry pyrolytic vapors within the solid charcoal particles and promote condensation of the vapors on the internal, and to some extent, the external surfaces of charcoal particles. The influence of pressure and residence time on formation of secondary char is illustrated in Figure 21.

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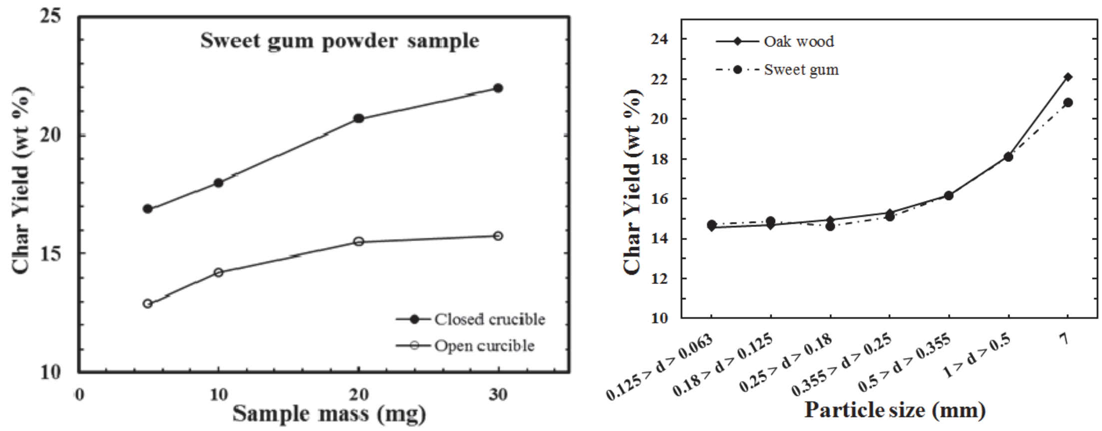


Figure 20: Effects of open vs. closed crucible (increasing pressure) (left) and particle size (right) on sweet gum powder charcoal yield.

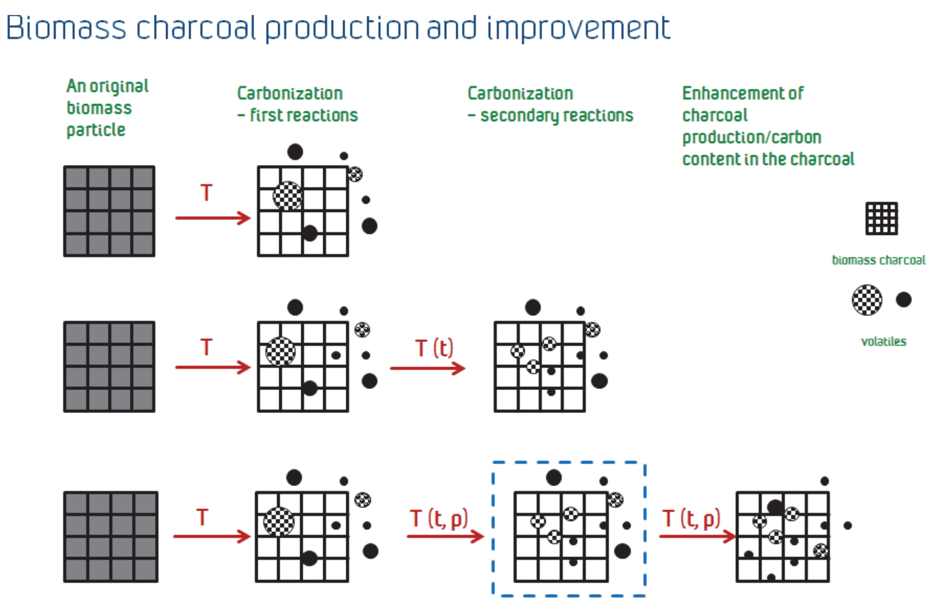


Figure 21: Influence of pressure and residence time on charcoal yield.

Under pressure, fixed-carbon yields obtained from some biomass species (e.g., corncob) reach up to 90% of the theoretical maximum values. The parity plot (see Figure 22) shows a significant increase of char yield from both oak wood and sweet gum by applying higher carbonization pressure.

Furthermore, charcoals produced at high heating rate and high pressure exhibit a molten morphology with smooth surface (see Figure 23). In this study, the factors influencing the charcoal yield and the fixed-carbon yield is thoroughly discussed, supported by extensive experimental work, and recommendations for attainment of high fixed carbon yields from biomass are given.

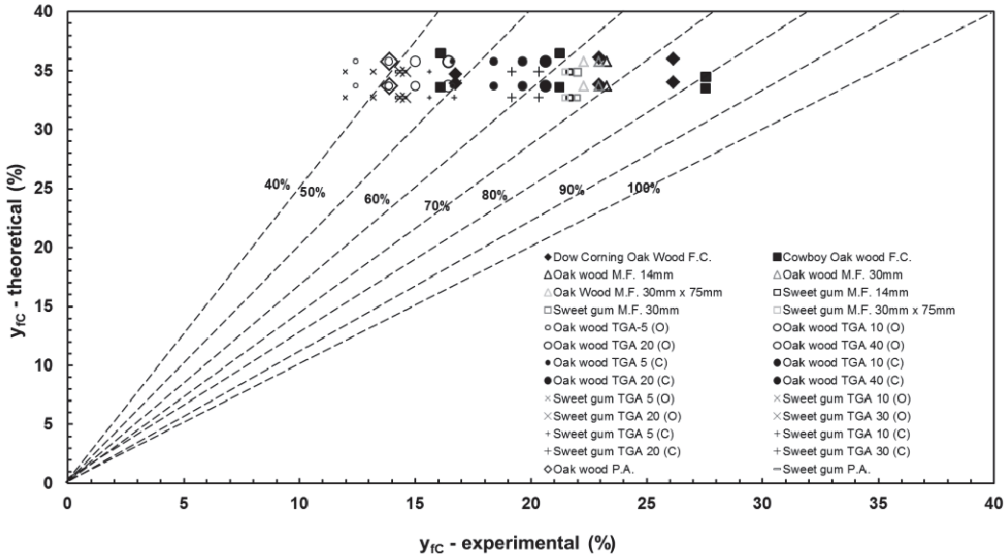
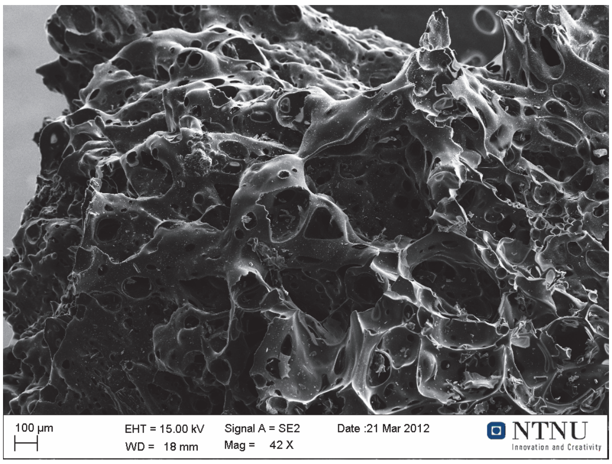


Figure 22: Parity plot displaying the experimental Flash Carbonization (F.C.), muffle furnace (M.F.), proximate analysis (P.A.), and thermogravimetric analysis (TGA) for open and closed crucibles (o, c) with various sample sizes in mg fixed-carbon yields vs. theoretical values based on the ultimate elemental analyses. [△, Oak wood; ●,○, Oak wood TGA; □, Sweet gum; ×+, Sweet gum TGA].



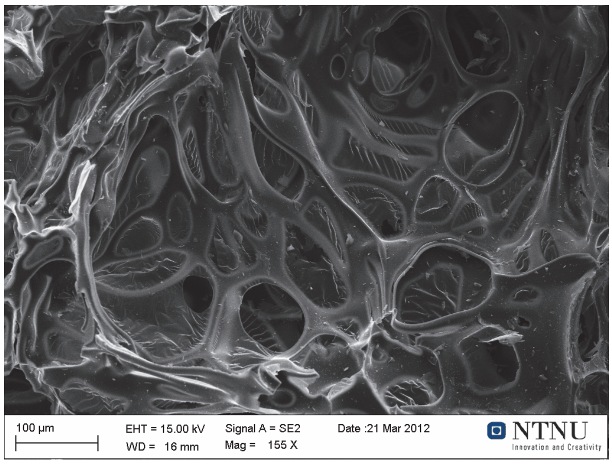


Figure 23: SEM micrograph of Cowboy oak wood charcoal sample produced in FC reactor at 2.17 MPa (at Hawaii University).

WP2.4 Anaerobic digestion

Increased energy yield from anaerobic digestion

The energy contained in organic material may be transferred into biogas by anaerobic digestion (AD). The main constituent of biogas is methane, a renewable energy source suitable for power/heat generation or as transportation fuel.

Anaerobic digestion offers an attractive option for the treatment of degradable organic wastes: besides lowering emissions of greenhouse gases, recycled organic-based fertilizers can be generated.

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In Norway, anaerobic digestion has so far mostly been used for waste water treatment, though it has recently attracted more attention as a way to produce renewable energy from manure and other organic waste streams. A political goal has been set to treat 30% of the manure by anaerobic digestion.

Most biogas processes produce far less methane than would be theoretically expected. CenBio aims at increasing the amount of renewable energy from AD, while ensuring a digestate quality that ensures nutrients' recycling.

Broadening the spectrum of feedstocks

Manure and domestic organic wastes are commonly used as feedstocks for AD. To produce more AD-based bioenergy, more organic material must be made available for AD processes. Biokraft AS has been planning, in collaboration with Fiborgtangen Vekst AS, Norske Skog ASA and Cambi AS, a large biogas production plant at Fiborgtangen in the municipality of Skogn. The planned biogas plant would be a commercial, so called "multi-fuel" plant using a mixture of available substrates, with a major fraction of fish-waste and wood fiber waste. Part of the mixture would go through thermal hydrolysis as pretreatment (the Cambi process) prior to digestion.

In 2012, a Master student from NTNU was engaged to do preliminary investigations with regard to this "multi-fuel" process. The main objective for the thesis was to obtain operation and biogas production data for the planned substrate mixture, and thereby, to evaluate the feasibility of the substrate mixture and eventually propose optimization measures. In more detail, the goals of this work were to:

I. Characterize the relevant substrate mixtures (fiber waste, biosludge, cattle manure, poultry manure and fish waste),

II. Evaluate the substrate mixtures with respect to biogas production, operational performance and stability,

III. Propose operational conditions and substrate mixture range based on the experimental results, and recommend future research in order to optimize the biogas production.

Preliminary results are promising but some obstacles needs to be solved.

Linjordet and co-workers studied the production of biogas from deep litter bedding materials. The basis of this study is that today's Fennoscandian animal husbandry has a high demand for appropriate litter material. Recently, use of locally produced woodchip-based bedding material proved generally feasible within animal production in Northern Norway. However, one considerable bottleneck of using woodchips is the appropriate utilization of the energy-rich bedding material. Hence, the study investigated the biogas potential of different litter bedding materials using anaerobic fermentation processes in laboratory-scale experiments. Biogas potentials of the studied substrates were generally low or negligible, but steam-exploded birch woodchips were apparently completely digested.

Improve digestibility

Digestibility of organic materials may be increased by enzyme treatment, maceration, hydrolysis, microorganisms, etc. Vivekanand and co-workers have investigated[22] the effect of different steam explosion conditions on methane production and saccharification of birch. The study shows that, during pretreatment of birch, increasing steam-explosion severities lead to degradation of xylan and formation of pseudo-lignin. The optimum pretreatment conditions for maximum

[22] Vivekanand V., Olsen E. F., Eijsink V. G. H., Horn S. J. *Effect of different steam explosion conditions on methane potential and enzymatic saccharification of birch*. Bioresource Technology, Vol. 127, pp. 343-349 (2013)

enzymatic glucose yield was determined, and steam explosion pretreatment was shown to increase biogas yield up to 81 %. Such high yields indicate that parts of the lignin and/or pseudo-lignin in steam-exploded birch could be used as a substrate for biogas production. The study also shows that optimal biogas yields are dependent on severities in the pretreatment, indicating that fine tuning of the pretreatment is important for efficient biogas production from lignocellulosic substrates.

Improve fertilizer quality of digestate

In field studies, we have demonstrated that AD digestate has comparable fertilizing effect on cereals as commercial mineral fertilizer does. In 2012, a 6 m^3 AD reactor has been successfully used to produce digestate from cow manure under quality assurance regime that ensured high quality and sufficient volume for use as manure in field studies with cereals.

National and international cooperation

CenBio's efforts within AD have been further strengthened by an extensive collaboration with internationally active research groups, particularly at the Swedish University of Agricultural Sciences, the Swedish Institute of Agricultural and Environmental Engineering, and Aalborg University (DK).

In April 2012, CenBio and Bioforsk co-organized an IEA Task 37 Workshop in Ås. International experts from different countries took the opportunity to discuss topics within "Biogas in the loop of recycling".

In June 2012, the "Cambi Biogas Summer Seminar" took place at Ås Campus. More than 40 participants from both the university and industry sectors attended this international seminar. The seminar covered all aspects of biogas research including pretreatment, enzyme technology, microbiology, digestate utilization and industrial applications. In addition to the presentations, the seminar also included separate group discussions on specific topics. Overall the seminar gave a nice overview of the state of the art of biogas research and industrial applications, and pointed out topics for future research. On the social side the seminar included a boat trip in the Oslo Fjord and a dinner.

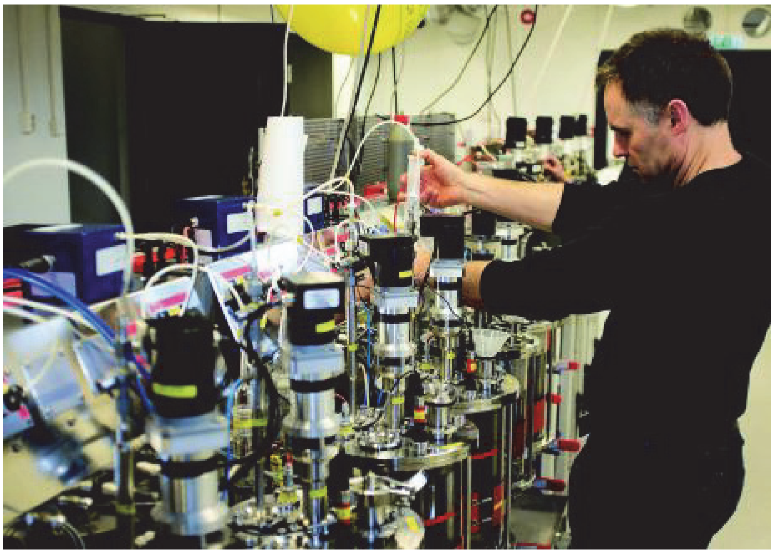

Figure 24: The Biogas laboratory at Ås campus. (photo: Ragnar Våga Pedersen, Bioforsk)

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WP2.5 KMB STOP: Torrefaction

In 2012, a lot of effort was put into setting up the torrefaction reactor in our Trondheim laboratory (see Figure 25). The control system had to be designed and fully tested before any experiments could be performed. The early operation of the reactor was proven quite challenging due to the high number of measuring nodes which had to be either logged or controlled. Most of the reactor early faulty behavior was corrected and, since September 2012, this reactor has been used quite extensively to produce different types of torrefied materials at various conditions. Both clean wood and fractions of tops and branches have been pelletized and torrefied at respectively 225 and 275 °C.

Pellets production and torrefaction have been part of this year's primary deliverable. The focus was on testing the combustion properties of these fuels in a pellet stove. The combustion properties of two raw fuels (stem wood, and GROT (branches and tree tops), a biomass with high ash content) and their torrefied counterparts have been assessed. This combustion study has concentrated on looking in detail at the flue gas emissions at different combustor loads. In particular, great attention was given to the effect of torrefaction on the fly ash particle size distribution and composition. The experimental campaign ended October 2012 and the resulting data have been treated. Figure 26 shows the particle size distribution for the clean wood at different combustor duty loads. The redaction of a journal publication based on this work started November 2012 and will be completed in the first half of 2013. The same torrefied fuels will be used in an experimental gasification study (within the RCN KMB GasBio project led by SINTEF-ER) carried out in collaboration with the Catalonia Institute for Energy Research (IREC). The effect of torrefaction severity, gasification temperature and pressure, and the use of different catalysts on the syngas quality will be parameters of interest.

The work on the torrefaction of birch and spruce in a macro-TGA has been finalized[23]. This work assessed the characteristics of two types of woods (hardwood and softwood) at different torrefaction temperatures, residence times and initial particle size (prior to torrefaction). The following findings were presented in the journal publication:

- The composition of the torrefied samples was found to be closer to coal, with higher carbon content and a lower volatile matter content.
- Birch was found to be more reactive than spruce. The birch exhibited a higher devolatilization rate and a lower solid yield than the spruce for all of the tested conditions.
- Of all the process parameters studied, the torrefaction temperature appeared to have the strongest effect on the biomass composition, devolatilization rate and solid yield.
- The hydrophobicity of the torrefied samples was much higher than the one of the raw samples. However, most of the benefits of this property were achieved after torrefaction at 225 °C with 30 min of holdup time, and the effects from further increasing the temperature or holdup time were limited.
- A 40–88% decrease in the total grinding energy was observed for the torrefied samples of both feedstocks. Among all of the tested process parameters, an increase in the temperature had the largest effect on the grinding energy.
- Torrefaction considerably increases the percentage of fine particles (<180 μm) in the particle size distribution after grinding. A uniform and similar particle size distribution was obtained for the samples torrefied at 275 °C.

[23] Tapasvi D., Khalil R. A., Várhegyi G., Skreiberg Ø., Tran K.-Q., Grønli M. *Torrefaction of Norwegian birch and spruce – an experimental study using macro-TGA*. Energy & Fuels, 26 (8), 5232-5240 (2012)

Figure 25: SINTEF-ER Research Scientist Roger A. Khalil working on the torrefaction reactor. (*photo: SINTEF/Thor Nielsen*)

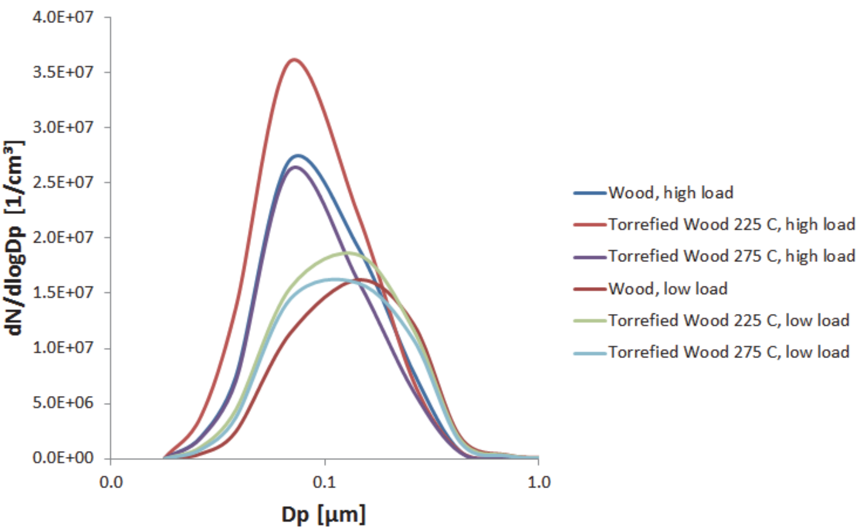

Figure 26: Particle size distribution for the clean wood at different combustor duty loads.

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In another work, the combustion kinetics of the aforementioned torrefied fuels has been studied[24]. A total of 42 TGA combustion experiments (both in air & at reduced O_2 concentration) have been performed with raw and torrefied spruce and birch. Three different temperature programs were used (linear, constant reaction rate and modular) in order to investigate the reaction kinetics in a wide temperature range. A journal publication based on this work is now finalized.

A simple Aspen Plus model for a torrefaction process has been developed for the calculation of mass and energy balances. The model includes a biomass rotary drum dryer, a torrefaction reactor and heat exchangers for the optimization of excess heat utilization. The model also integrates combustion of gases and liquids produced in the torrefaction step. The heat produced is recycled in order to provide energy for the torrefaction and drying steps. It is also possible to add a utility fuel (natural gas) in the combustion step in case more energy is needed. Data from the model are used for cost efficiency analysis of a torrefaction plant. The model attempts to estimate the costs of torrefaction per kg produced torrefied material. A sensitivity analysis includes the variation of important parameters, such as plant size, torrefaction temperature, moisture content in the initial fuel, etc. Some of the results have been presented at the project's annual workshop, arranged in December 2012.

[24] Tapasvi D., Khalil R. A., Varhegyi G., Skreiberg Ø., Tran K.-Q., Gronli M. G. *The kinetic behavior of torrefied biomass in an oxidative environment.* Energy Fuels, *27* (2), pp. 1050–1060 (2013)

SP3 CONVERSION TECHNOLOGIES AND EMISSIONS

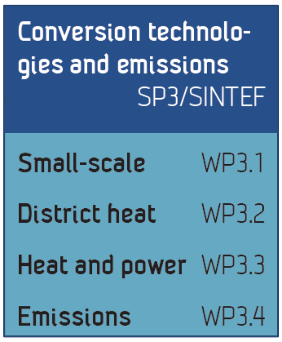

Figure 27: WBS of SP3.

Øyvind Skreiberg
Leader of Conversion Technologies and Emissions
(photo: SINTEF)

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 CenBio Vision 2020 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 plants converting biomass to energy 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 standardization of testing methods related to EU directives. Recently, a novel solution was finalized for an increased convective heat transfer from the exhaust gas after the combustion chamber, leading to up to 45 % higher heat output during the first hour of operation.

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 on the spotlight. They are investigated through four approaches:

- Plant emissions mapping (e.g., Energos/Hafslund WtE plant at Borregaard in 2012);
- CFD modeling;
- Experimental studies;
- Literature surveys (e.g., NOx reduction methods).

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Innovations from SP3 are initially expected in the following areas:

- New efficient clean-burning stoves and fireplaces;
- Concepts for ultra-efficient district heating plants, possibly utilizing biogas and solid waste in synergetic combination;
- Concepts for heat and power plants with close to 100 % combined energy efficiency;
- New recipes for low-emission plants.

WP3.1 Small-scale wood / pellet stoves

Today, small-scale wood combustion in wood stoves accounts for half of the bioenergy use in Norway (about 7 TWh in 2010), and the use of wood logs in small-scale units and pellets in pellets stoves is expected to increase substantially towards 2020. The goal of this work is to increase the energy output from those units with 10 TWh 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 utilization of firewood is expected to substantially increase within the next decade, it is essential to ensure that harmful emissions (e.g., particles) are minimized, and that national requirements and regulations are uphold and improved. Those considerations should not be relaxed by new EU directives not taking into account the special Norwegian conditions. Partial load performance is very important, since firing at partial load will be the typical situation in Norway. Standardization of testing methods is then a key issue, through active participation in the international standardization 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.

In 2012, the experimental activity focused on testing particle emission measurement methods, including particle size distribution, in order to further expand our analysis capabilities and experimental output, and to aid in the continuous particle emission reduction effort. A so-called DustTrak laser-based particle emission measurement equipment was tested against both an Electrical Low Pressure Impactor (ELPI) and a gravimetric impactor. The results are qualitatively comparable, though quantitatively, significant differences in the results can be found. This is partly due to the different measurement principles and how the measurement equipment is calibrated. All 3 particle emission measurement equipments give useful information if used correctly, and will provide needed information for our further particle emission reduction efforts. Figure 28 shows the 3 particle emission measurement equipments.

Figure 28: Particle emission measurement equipments (From left to right: DustTrak, ELPI and gravimetric impactor).

WP3.2 District heat

In 2012, no less than three exciting research themes were explored:

- Oxygen enhanced combustion (OEC) for biomass
- Combined Cycles for Waste to Energy (WtE)
- Potential use(s) of fly ash from WtE

Oxygen Enhanced Combustion (OEC) for biomass

Research scientist Roger Khalil gave a presentation at the Technoport RERC Research Conference in Trondheim (April 2012) on the topic of OEC for biomass. An overview of the current knowledge/experience on OEC for biomass with a focus on the most significant pros and cons was given.

In short, OEC is a thermal treatment method where the oxidizing agent has an oxygen concentration higher than air (21%). This method is used in various applications especially when high temperatures are required to, for example, destroy contaminants.

Limited research has been done so far on the subject for biomass, though relevant knowledge can be extracted from the work done on waste (and coal). The main identified benefits and drawbacks are listed in Table 4.

Table 4: Main identified benefits and drawbacks from Oxygen Enhanced Combustion for biomass.

Benefits	Drawbacks
Increased throughput	Refractory damage due to overheating and corrosion
Higher thermal efficiencies	Non uniform heating
Lower exhaust gas volumes	Increased NOx emissions
Higher heat transfer efficiency	Higher noise levels and possibility for flashback incidence
Reduced equipment costs	
Reduced raw material costs	
Increased flexibility of heating system	
Reduced refractory wear	

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Further experimental work is required to better draft the potential of OEC for biomass related applications. Some experimental work has been performed at SINTEF Energy Research as a first evaluation.

Combined Cycles for WtE

The increasing focus on sustainability and renewability, as well as the legislative context in the EU, are pushing for higher efficiencies in waste to energy (WtE) facilities. Combinations of a waste incinerator together with another power cycle in so-called dual-fuel combined cycles appear as a promising alternative to increase efficiency. In these systems, the waste incineration process obtains (part of) its heat supply from the exhaust gas of another power cycle, most commonly, a gas turbine.

Calculations and existing installations have shown that combined systems, without exceptions, will:

- Deliver a larger energy output than two stand-alone sub-cycles;
- Deliver higher efficiencies compared to two stand-alone sub-cycles; typically 1-5 percentage points higher than two stand-alone sub-cycles;
- Lead to reduced specific CO_2 emissions (kg/kWh).

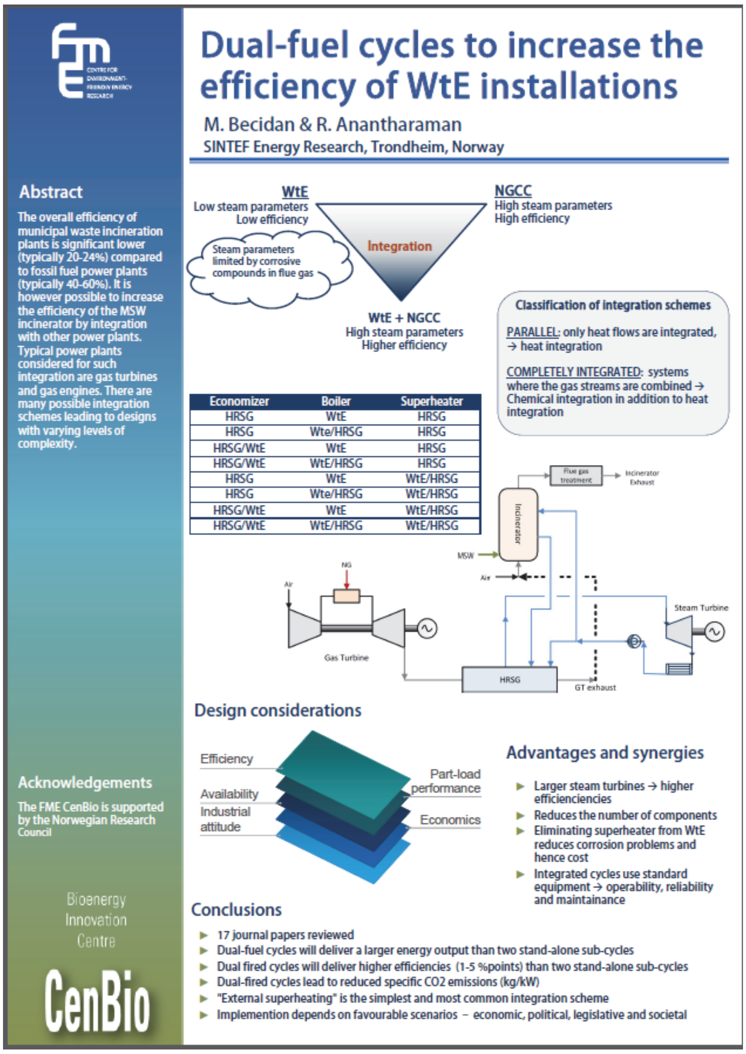

Figure 29: Dual-fuel cycles involving WtE.

In 2012, a brief literature overview on the topic was published as a peer-reviewed conference paper[25] and presented as a poster at the 15th PRES Conference[26]. The conference poster is reproduced in Figure 29.

Fly ash from WtE

Fly ash from WtE is classified as hazardous wastes in Norway and has to be disposed of in a dedicated landfill located on the island of Langøya in the Oslofjord. This is the only solution currently and represents a significant cost to the plant owners. Are there any alternative solutions turning this residue into a resource? The present work has been thoroughly searching for such opportunities.

Solutions which recycle and recover as much as possible of the valuable components of the MSWI fly ash are the most suitable. Previously mentioned recycle and reuse of waste will not only consider an elimination of waste, but also use of 'zero-cost' raw material and conservation of natural resources.

Solidification/stabilization processes, so called S/S, do not seem plausible for MSWI fly ash, since they contain high levels of salts and the leaching of these salts from the S/S matrix over time is likely to result in poor performance. The direct use of MSWI fly ash as a blending material in products, such as bricks and tiles, does not seem realistic. MSWI fly ash is too hazardous to be used "as is".

Vitrification appears as a safe way to manage MSWI fly ash, but the energy demand is high, the usage is limited and it does not lead to high value products. This technology is much used for fly ash from coal fired power stations. One drawback is the secondary fly ash from the vitrification, which requires further treatment. Attention should be placed on reducing the energy consumption. One option might be to vitrificate the residue after metal recovery.

A promising method is the Carrier-in-Pulp (CIP) method. This is largely due to its simple operation and low energy requirement. An activated carrier (e.g. carbon, iron) acts like a sponge to complex ions in the solution and because the carrier particles are much larger than the fly ash particles, the coarse carrier can be separated from the slurry by screening. Since most metals are adsorbed on the carrier and the solution becomes free of metals, the CIP method offers the great advantage of not requiring a washing or stabilization process for the discharge. To the authors' knowledge, CIP has not been tested in large scale, though the technology is widely used as an extraction technique for the recovery of gold.

The willingness to contribute to research and development, and also to make use of new technology, has much to do with the population density and access to landfills in this matter. In Canada, all MSWI fly ash (and almost all MSW) is disposed of in landfills, whereas in contrast, Japan has a handful of different advanced treatments of hazardous waste (including re-use), with landfill as a last option. Switzerland is also a leading actor, especially when it comes to metal recovery.

There is a need for incentives and regulations favoring alternative solutions to landfilling. The solution in Norway is the landfill at the Langøya island near Oslo, which also receives MSWI fly ash from Denmark, Sweden and Finland. The latest estimates show that the landfill at Langøya is expected to be full by 2023-2025. After closure, the island is expected to be used for recreational activities. What should be done then?

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[25] Becidan M., Anantharaman R.; *Dual-fuel cycles to increase the efficiency of WtE installations*; Chemical Engineering Transactions, 15th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, 29; pp. 727-732 (2012)

[26] 15th PRES Conference 2012, 25-29 August 2012, Prague, Czech Republic, www.chisa.cz/2012

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WP3.3 Heat and power

CenBio aims for close to 100 % combined energy efficiency

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

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

- Assess the potential for efficiency improvements through improved combustion process control and process integration in industrial heat plants, and to assess the cost-efficiency potential of this,

- Assess the potential for emission reduction through efficiency improvements, fuel modifications and operational changes.

Several technology options exist for CHP plants (e.g., steam turbines, gas turbines, gas engines, Organic Rankine Cycle (ORC), Stirling engine, etc.) suitable for different plant sizes. However, they differ with respect to achievable efficiencies, operational reliability and costs. In addition, combinations of different CHP technologies can be applied to further increase the electric efficiency, e.g., combined cycles or gasification in combination with ORC. Hence, for a significant introduction of biomass- and MSW-based CHP in Norway, it is essential to assess the suitability of the existing technologies and the potential for further improvements with respect to cost-efficiency and emission abatement, including framework conditions, and operational optimization. In 2012, a pop-tech. article on the status of biomass CHP in Norway, and the way forward, was published in Xergi[27]. 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

[27] Øyvind Skreiberg; *Biomasse kraft-varme (CHP) i Norge – Hvor står vi og hvor går vi?*; Xergi, Nr.3 Dec. 2012

from biomass, though, with a value of about 15 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.

ChlorOut is a corrosion and fouling reducing concept for biomass fired boilers, as well as for NOx, CO and dioxin reduction. The use of ChlorOut in waste wood, demolition wood and waste residue fired boilers has not been fully developed yet. Tests will be done in the Jordbro-plant (see Figure 30), south of Stockholm, in cooperation with Vattenfall AB, BU Heat. The plant is a BFB, 63 MW_{th}, 20 MW_{el}, with the steam data 470°C/80 bar. It is designed for wood fuels, e.g., demolition wood and forest residues. The corrosion on superheaters will primarily be studied, as well as the impact on emissions.

The goals are to:

➢ Decrease the corrosion rate by at least 50%,

➢ Decrease fouling and decrease the dioxin emissions with at least 50% in a waste wood/biomass fired CHP-boiler.

Figure 30: The Jordbro power plant. (photo: Vattenfall)

From 2010 until March 2011 installation of the ChlorOut injection system was carried out. The next phase started in April 2011, namely start-up and optimization to achieve minimum corrosion rate and maximum NOx and CO reduction. This crucial work continued throughout 2012. Vattenfall BU Heat has performed installation of the hardware associated with the ChlorOut system in the Jordbro CHP plant. The installation work includes planning, engineering, manufacture, assembly and commissioning of the equipment. The equipment comprises a 40 m^3 storage tank, a pump station with associated installation and commissioning, pipes to boiler house top, an intermediate storage tank (~2 m^3) in boiler house, dosing pumps, lances etc. Furthermore, BU Heat has been involved in the planning, performance and evaluation of the ChlorOut short-term testing managed by VRD. The installation work has been successful, although there are still some open tasks regarding the large storage tank and the pumping station that still have to be solved.

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WP3.4 Emissions

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).

The emission of acidifying and polluting nitrogen oxides (NO_x) in 2010 ended 19 % above Norway's obligation set in the Gothenburg Protocol (Ref. SSB). Even if energy from biomass is not of the most significant contributor to the Norwegian NOx emissions, higher production of district heating is mentioned as one of the contributors to the increased emissions of NOx from 2009 to 2010, together with increased activity in the manufacturing industries and higher production of gas power (Ref. SSB).

Wood stove combustion in Norway is a major contributor to some harmful emissions to air: 2/3 of the particle emissions and 1/3 of the PAH and dioxin emissions originate from combustion in wood stoves.

This emphasizes that emissions from waste and biomass combustion are a continuous concern and continuous efforts with respect to emission minimization 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 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 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 31) was utilized 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, a necessity to be able to perform advanced measurements and obtain high quality results.

The planning of a similar measurement campaign to be carried out at the Akershus Energi BtE-plant in 2013 has started recently. Extensive emission measurements such as those have hardly been carried out earlier at Norwegian BtE plants.

Figure 31: FTIR gas sampling and conditioning unit. (photo: Sascha Njaa, SINTEF)

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

Emission modeling

Tools and methods to study emissions from biomass and waste conversion units will be developed. CFD modeling will be an essential part of this work, and combined with detailed chemical kinetics for the gas phase reactions, which is a necessity when modeling fuel 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. In 2013, modeling work will be carried out to assess the NOx reduction potential using CFD, which will be compared with earlier experimental results.

The calculation results will also be verified towards DARS calculations (WP1.3 and 2.1). The outcome will be a numerical tool that can be used to study NOx emissions and NOx reduction potential from biomass conversion.

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

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SP4 SUSTAINABILITY ANALYSIS

Birger Solberg
Leader of Sustainability Analysis
(photo: Håkon Sparre)

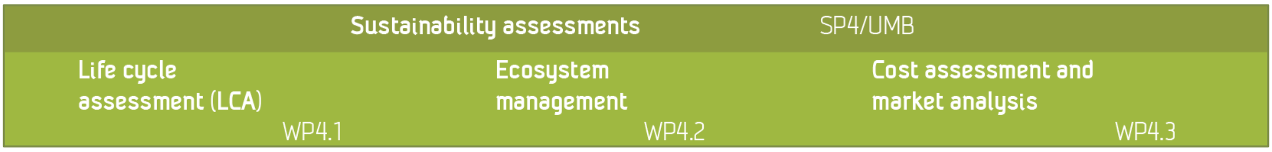

Figure 32: WBS of SP4.

SP4 focuses on the establishment of documentation on the sustainability of bioenergy value chains, based on existing results and those obtained from all the other CenBio work packages. SP4 is divided between extended Life Cycle Assessment (LCA), ecosystem management, and work on costs, markets, policies and integrated sustainability analyses.

The work on extended LCA investigates GHG emissions over time, albedo and indirect GHG impacts. A new method has been developed to account for the environmental impact and CO_2 emissions from biomass combustion in bioenergy systems. This resulted in the highly ranked Laudise Medal being awarded to Professor Anders H. Strømman from NTNU in 2011. In the USA, this work has been used by the US Environmental Protection Agency (EPA), which is formulating the new normative framework for biogenic CO_2 emissions.

The work on ecosystem management is essential for several reasons. When woody biomass is harvested, important nutrients are removed from the forest soil. In CenBio, studies have been carried out comparing stem-only thinning versus whole-tree thinning. The results have given the first Norwegian-based empirical database on the issue, and are in accordance with recent Swedish and Finnish trials.

Research on costs, markets, policies and integrated sustainability analyses has focused on developing a spatial partial equilibrium model, incorporating both forestry, forest industries and wood-based bioenergy production. This enables to analyze how international market and policy changes may influence the Norwegian biomass markets. CenBio researchers have participated in the European Forest Sector Outlook Study II (EFSOS II) led by the FAO and the UN Economic Commission for Europe. While the share of wood trade in total wood and wood based products imports has remained stable, the importance of wood chips and wood based residues has risen significantly in the last few years. The main reason is the trade of pellets, and it is expected that the trade of chips and wood residues and pellets will grow because of the EU RES 2020.

WP4.1 Extended Life Cycle Assessment

The role of WP4.1 is to investigate the climate impact of CO_2 emissions from bioenergy and biomaterials. Harvest disturbances of forests can alter biogeochemical and bio-geophysical mechanisms, thus affecting local and global climate. Following IPCC climate metrics, we assess bioenergy systems in light of two important dynamic land use-climate factors, namely, the perturbation in atmospheric carbon dioxide (CO_2) concentration caused by the timing of biogenic CO_2 fluxes, and temporary perturbations to surface reflectivity (albedo).

Results show the importance of specifically addressing the climate forcings from biogenic CO_2 fluxes and changes in albedo, especially when biomass is sourced from forested areas affected by seasonal snow cover. The climate performance of bioenergy systems is highly dependent on biomass species, local climate variables, time horizons, and the climate metric considered. Bioenergy-related climate policies and accounting mechanisms should rapidly adapt to address these issues and the complexity of the outcomes.

Climate impacts of biogenic CO_2 emissions: IRFs and GWP

We treat biogenic CO_2 emissions as the other greenhouse gases (GHG) following IPCC climate metrics based on the concept of radiative forcing and Global Warming Potential (GWP). This approach is the most common way to deal with GHG emissions in environmental impact studies, life-cycle assessment (LCA) studies, and climate impact accounting mechanisms.

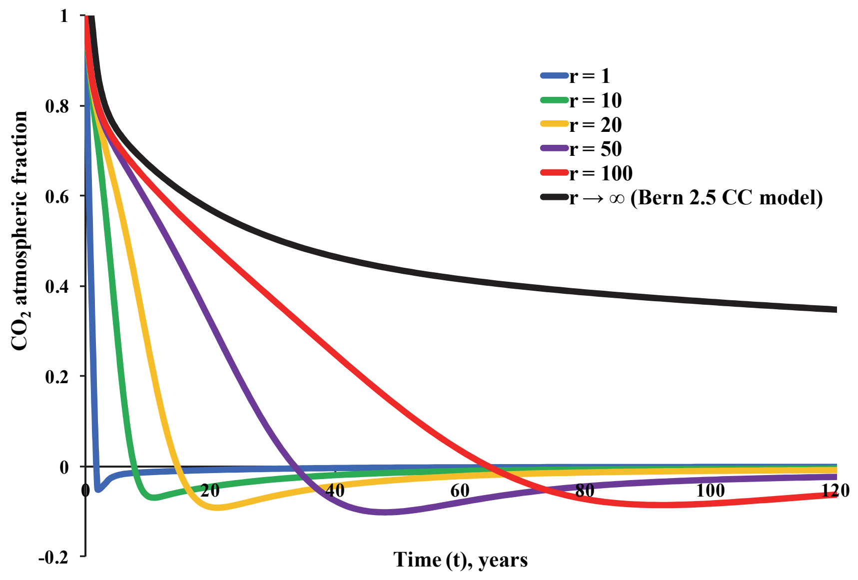

Figure 33: IRF of biogenic CO_2 from regenerative biomass in comparison with the decay of fossil CO_2 (or from deforestation), and as a function of the biomass rotation period (r). Source: [28]

Climate metrics refer to the impact of a pulse emission of the GHG to the atmosphere. This is assessed by predicting the atmospheric decay of that pulse emission using the so-called Impulse Response Function (IRF). IRF is the fraction of the emission pulse remaining in the atmosphere over time. Therefore, we have elaborated[28,29] IRF for biogenic CO_2 emissions as a function of the biomass

[28] Cherubini, F., et al., *CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming*. GCB Bioenergy, 2011. 3(5): p. 413-426.

[29] Cherubini, F., A.H. Strømman, and E. Hertwich, *Effects of boreal forest management practices on the climate impact of CO_2 emissions from bioenergy*. Ecological Modelling, 2011. 223(1): p. 59-66.

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rotation period, integrating the biomass system with the global carbon cycle, and simulating an idealized scenario, where all the above ground standing biomass is harvested. Figure 33 shows the atmospheric decay of biogenic CO_2 from regenerative biomass.

GWPs of biogenic CO_2 for bioenergy from biomaterials

Harvested biomass can be used as materials and stored in the anthroposphere for a certain number of years before being used for bioenergy production. In this case, biogenic CO_2 emissions from bioenergy occur at the end of life of the biomaterials, while the sequestration in the new stand occurs immediately after harvest, thus, sequestering CO_2 from the atmosphere before than the harvested biomass is combusted. We have investigated the value of the GWP (Time Horizon (TH) = 100) to characterize biogenic CO_2 emissions as a function of the biomass rotation period and of the storage period in the anthroposphere[30]. Figure 34 shows that the value of GWP is almost zero (i.e., no effect on climate) when the harvested biomass is stored for approximately half of the rotation period.

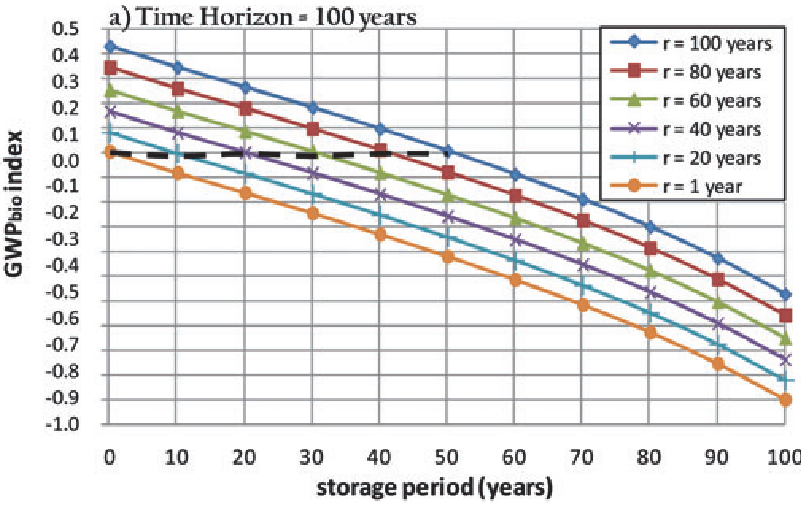

Figure 34: GWP factors (TH = 100) for 6 rotation periods (r) as a function of biomass storage period in the anthroposphere. The black dash-line shows when the storage period equals to half the rotation period. Source: [30]

Effect of timing of biogenic CO_2 emissions from harvested wood products on GWP

Another part of the work in WP4.1 has been to investigate[31] the different options to model biogenic CO_2 emissions from biomass harvested for biomaterials, considering three wood applications with different lifetime: fuel (lifetime = 2 years), non-structural panels (lifetime = 30 years), and housing construction materials (lifetime = 150 years). CO_2 emissions from wood oxidation are modeled using the following probability distributions:

a) A delta function (δ), used to simulate emissions at the end of the lifetime, as in the section above;

b) An uniform distribution (υ), where emissions are equally spread over a certain number of years (equal to two times the lifetime);

c) An exponential distribution (ε), following IPCC practices for harvested wood products;

[30] Guest, G., Cherubini, F. and Strømman, A. H. (2013), *Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life*. Journal of Industrial Ecology, 17: 20–30. doi: 10.1111/j.1530-9290.2012.00507.x

[31] Cherubini, F., G. Guest, and A.H. Strømman, *Application of probability distributions to the modeling of biogenic CO_2 fluxes in life cycle assessment*. GCB Bioenergy, 2012. 4(6): p. 784-798.

d) A chi-square distribution (χ), where the emissions are distributed around the expected lifetime.

Figure 35 shows on the left the profiles of the CO_2 emission rate given by the different probability distributions for wood use as non-structural panel, and on the right the resulting changes in atmospheric CO_2 concentration, i.e. IRF (that is labeled PRF in the figure).

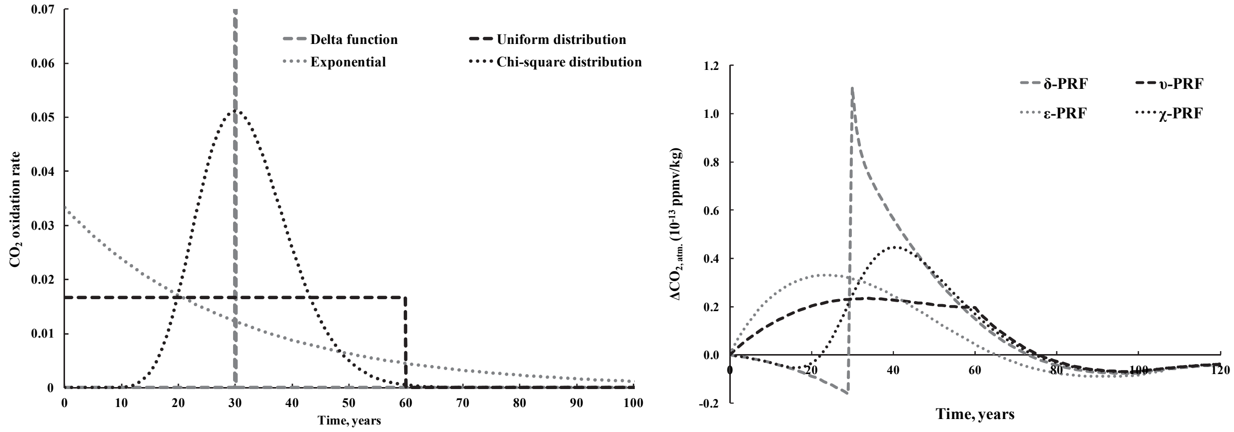

Figure 35: Oxidation rates according to different probability distributions for wood use as non-structural panel on the left. Corresponding changes in atmospheric CO_2 concentration are shown on the right. Source: [31]

Role of forest residues for IRF and GWP

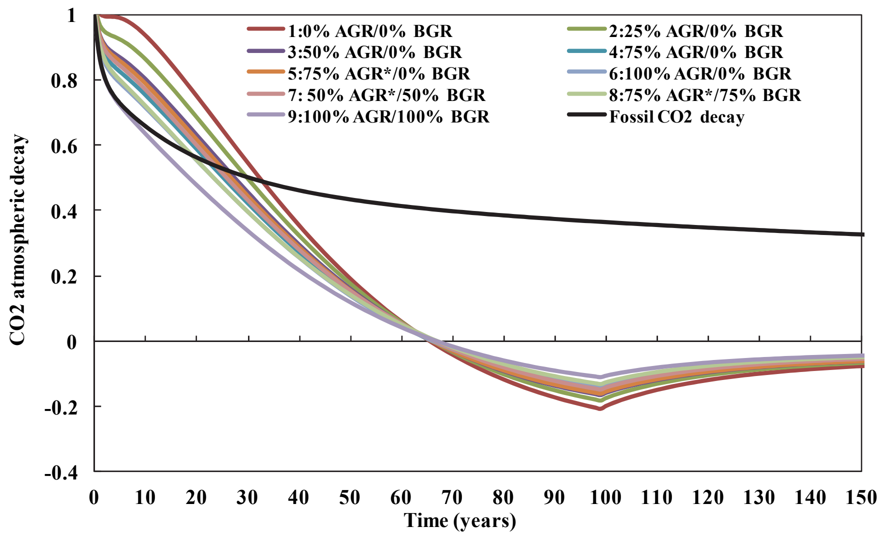

Figure 36: Atmospheric CO_2 decay profiles due to a unit CO_2 pulse of bioenergy at conversion site with consideration of CO_2 emissions due to decomposition of the fraction of forest residues that remain upon the forest floor. AGR = Above Ground Residues; BGR = Below Ground Residues. % refers to the fraction of residue that is harvested. Source: [32]

The influence for GWP of biogenic CO_2 of harvesting forest residues along with the stems has been investigated[32] (case study: Norwegian spruce forest). Figure 36 shows the resulting different IRFs resulting from various forest residue removal scenarios. The IRFs and GWP factors appear to be

[32] Guest, G., Cherubini, F. and Strømman, A. H. (2012), *The role of forest residues in the accounting for the global warming potential of bioenergy*. GCB Bioenergy. doi: 10.1111/gcbb.12014

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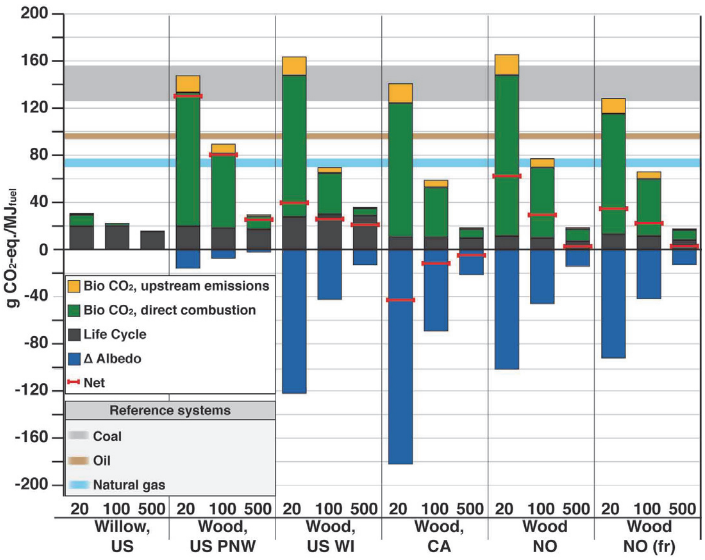
sensible to the amount of forest residues harvested. When all residues are left in the forest (red line in Figure 36), they freely decompose over time, so that the biogenic CO_2 decay is slower for some decades than that of fossil CO_2. When all residues are collected (light purple line in Figure 36), the decay is faster and perfectly overlap with that shown in the second section above. For a 100-year time horizon, the GWP factors suggest that between 44 and 62% of biogenic CO_2 emissions at the energy conversion plant should be attributed to causing equivalent climate change potential as fossil-based CO_2 emissions.

Site-specific GWP and the importance of albedo

The peer-reviewed literature about climate impacts from forest management reports important contributions from changes in biophysical factors like surface reflectivity (albedo), long wave radiation fluxes, evaporation and others[33,34]. For example, the albedo effect is found to be the dominant direct bio-geophysical climate forcing on the global scale, particularly in areas affected by seasonal snow cover, and can sometimes more than offset the global warming induced by deforestation [34]. In a recent paper[35], we assess the contributions to direct global warming of various bioenergy case studies from temporary climate forcings as changes in atmospheric CO_2 concentration and surface albedo, in addition to direct greenhouse gas (GHG) emissions throughout the value chain. The analysis focuses on CO_2 from bioenergy sourced from a stand where biomass is kept under continuous rotation (no land use change), and a LCA perspective is undertaken. Figure 37 shows the contributions for the various case studies when biomass is used for production of heat in stationary plants. When biomass is sourced from areas affected by seasonal snow cover, albedo contributions are significant, and in some cases, they can more than offset the global warming induced by GHG emissions, so giving a net cooling effect also in the very short term (e.g., see CA case study).



Abbreviations:
PNW = mixed forest in Pacific Northwest (US);
WI = aspen forest in Wisconsin (US);
CA = pine forest in Canada;
NO = spruce forest in Norway;
fr = with harvest of 75% of above ground forest residues;
Bio CO_2 = biogenic CO_2 emissions, i.e. emissions from oxidation of biomass harvested for bioenergy;
Upstream emissions = emissions from biomass losses through the value chain and biofuel processing;
Direct combustion = emissions from combustion of biofuels at plant.

Figure 37: Direct contributions to global warming of different bioenergy options for stationary applications. 3 time horizons (20, 100 and 500 years) are considered. Fossil fuels (coal, oil and natural gas) per MJ of fuel combusted are shown to benchmark our results. Lower and higher limits of the bands for the fossil systems represent the impact for TH = 500 and TH = 20, respectively. Source: [35]

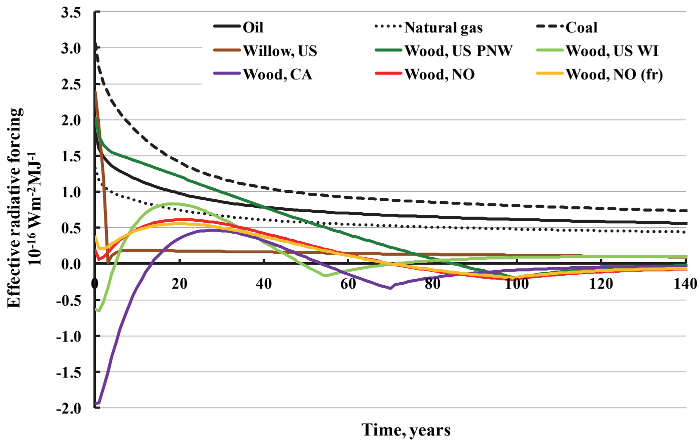
[33] Bright, R.M., F. Cherubini, and A.H. Strømman, *Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment*. Environmental Impact Assessment Review, 2012. 37: p. 2-11.

[34] Bright, R.M., A.H. Strømman, and G.P. Peters, *Radiative Forcing Impacts of Boreal Forest Biofuels: A Scenario Study for Norway in Light of Albedo*. Environmental Science & Technology, 2011. 45(17): p. 7570-7580.

[35] Cherubini, F., R.M. Bright, and A.H. Strømman, *Site-specific global warming potentials of biogenic CO_2 for bioenergy: contributions from carbon fluxes and albedo dynamics*. Environmental Research Letters, 2012. 7(4).

Importance of climate metrics

GWP is a form of cumulative metric, i.e., it considers the cumulative/integrated effect over time of a perturbation in terms of radiative forcing. When instantaneous metrics are considered[36] (i.e., the instantaneous impact at a specific point in time), such as instantaneous radiative forcing or global surface temperature change, the impact from bioenergy is shorter in time than that from fossil CO_2. Figure 38 shows the case studies presented above for production of heat in comparison with fossil systems using the temporal changes in instantaneous radiative forcing over time. In the short term, impacts from bioenergy can be lower than that of fossils, or even net negative (i.e., yielding a cooling effect). Concerning the medium- and long-term, bioenergy impacts are basically temporary, as they tend to be very low after some decades, while those from fossil fuels are consistently higher.



Abbreviations:
PNW = Pacific Northwest (US);
WI = Wisconsin (US);
CA = Canada;
NO = Norway;
fr = with harvest of 75% of above ground forest residues.

Figure 38: Net effective radiative forcing (instantaneous) for the different bioenergy options for stationary applications and fossil reference systems. Source: [35]

Figure 39 compares the global average surface temperature response to a pulse emission of fossil CO_2 and biogenic CO_2 sourced from regenerative biomass (rotation period = 100 years) [9]. The curves show that CO_2 emissions from deforestation or combustion of fossil fuels induce a response that warms global average surface temperature for millennia, while CO_2 emissions from forest bioenergy warm climate only temporarily. Should increases in the demand for forest bioenergy lead to reduced carbon stocks rather than full recovery of the pre-harvest forest, the resulting climate response should still be understood as being principally different from that of fossil CO_2 or from deforestation, having a profile that lies somewhere in between the two cases presented in Figure 39.

[36] Bright, R.M., et al., *A comment to "Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral": Important insights beyond greenhouse gas accounting*. GCB Bioenergy, 2012. 4(6): p. 617-619.

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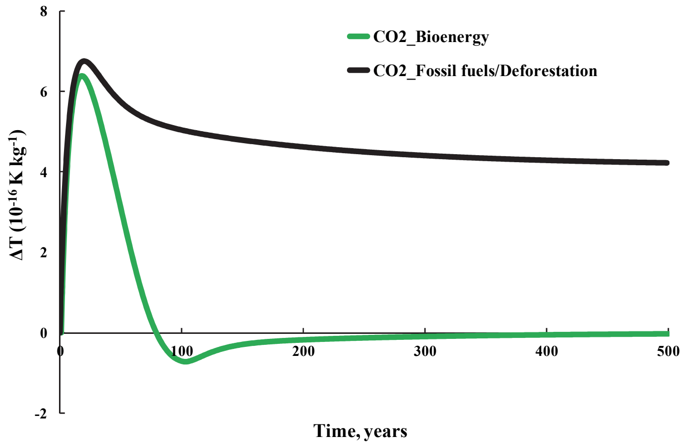


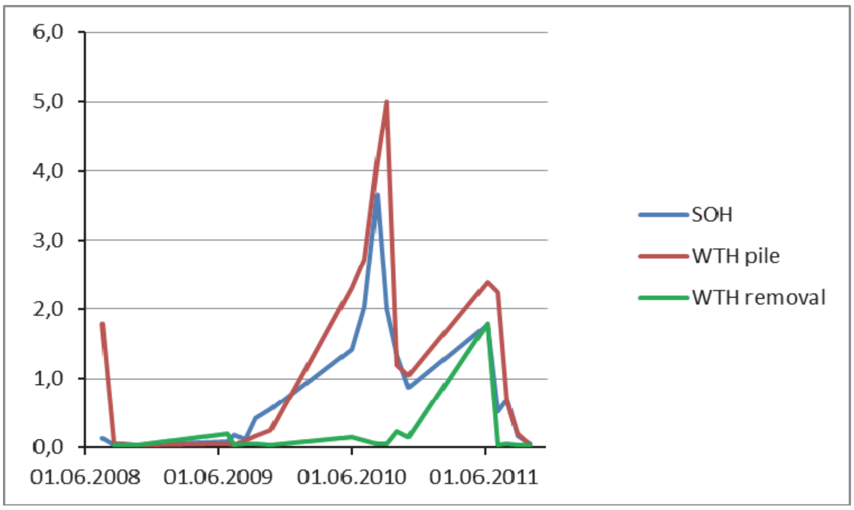
Figure 39: Global surface temperature response to a pulse emission of fossil CO_2 in relation to the same pulse from bioenergy sourced from a forest in which carbon stock is regenerated over a 100-year rotation period. Source: [36]

WP4.2 Ecosystem management

Main achievements 2012

- A chapter in book[37] has been published as a result of an investigation of the ecological consequences of increased biomass removal for bioenergy from boreal forests.

- A report[38] has been prepared about the effects of harvesting on soil water chemistry, with data from the Gaupen field experiment. Soil water concentrations of many nutrients showed large increases after harvesting, although with variation according to harvesting type, as shown in Figure 40 and Figure 41.



Abbreviations:

SOH = stem-only harvesting,

WTH = whole-tree harvesting (sub-divided into areas with removal of forest residues and areas in which forest residues were piled).

Figure 40: Effects of harvesting type on concentrations of nitrate-N (mg/l) in soil water at the Gaupen field experiment. Harvesting took place in March 2009 and residues were removed in September 2009. The post-harvest leaching of nitrogen is clearly shown. Source [38]

[37] Nicholas Clarke; Garcia, J.M. & Casero, *Ecological Consequences of Increased Biomass Removal for Bioenergy from Boreal Forests (Chapter 9)*; J.J.D. (eds.): *Sustainable forest management/Book 1*; InTech 2012

[38] Nicholas Clarke; *Effects of forest harvesting on soil water chemistry: preliminary results from the Gaupen field experiment*; Public technical report from NFLI, 2012

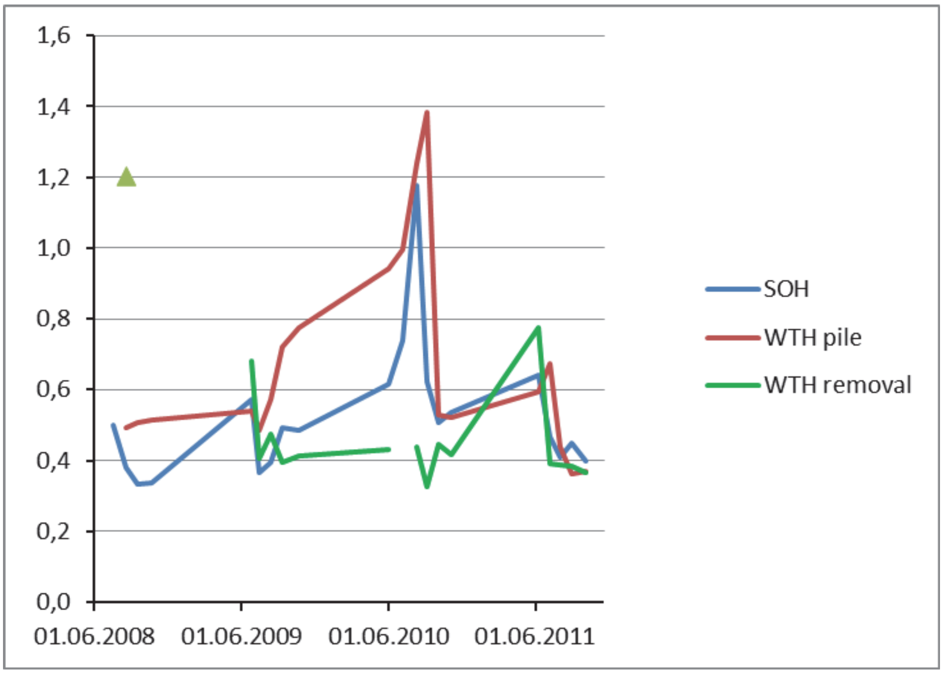


Figure 41: Effects of harvesting type on concentrations of Mg (mg/l) in soil water at the Gaupen field experiment. See details in Figure 40. Source [38]

- A survey of forest management guidelines from countries comparable to Norway has been completed, and a report prepared[39]. In some areas, such as soil nutrient management and terrain damage, other countries have very detailed guidelines, so that it may be possible to learn from their experience.
- A preliminary survey has been carried out about the effects of harvesting and removal of branches and tops on soil C stocks, and a report prepared[40]. Harvesting often has a large negative effect on the amount of organic matter in the soil's organic horizon, although there may be an apparent increase in the amount of organic matter in the mineral soil. There are also variations according to harvesting type, with lower soil C observed in the mineral soil after whole-tree harvesting than after stem-only harvesting.
- Laboratory studies of the effects of harvesting type on soil fungi at the Gaupen field experiment are being completed using a new technique. A report will be prepared in 2013.
- Field sampling has been carried out to investigate heavy metal concentrations in forest soils (relevant when considering wood ash spreading).

Expectations for 2013 and next 3-4 years

Starting from 2013, the main focus of WP4.2 will change from ecosystem studies in the field to innovations in terms of inputs to management guidelines and other forms of governance. We plan to finalize four peer-reviewed journal publications in 2013 dealing with:

(i) Results from long-term experiments,

(ii) Modeling,

[39] Tuyet Lan Phan, Nicholas Clarke; *Comparison of forest management guidelines for sustainable harvesting of biomass for bioenergy*, Public report from NFLI, 2012

[40] Nicholas Clarke; *Effects of forest harvesting and slash removal on soil carbon stocks*, Public technical report from NFLI, 2012

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(iii) Harvesting effects on soil organic carbon,

(iv) Soil sustainability guidelines.

Future work (2014-2016) will include:

- Further journal publications (notably about the Gaupen field experiment);
- The completion of one PhD thesis on modeling;
- Recommendations for sustainable harvesting of biomass for bioenergy from Norwegian forests;
- Contribution to the development of international standards;
- Studies on environmental performance for biomass value chains;
- Criteria and indicators for environmentally and economically sound management of biofuel resources.

International cooperation

- Participation in a Nordic network on forest soil carbon (effects of harvesting on soil organic carbon);
- Participation in a Nordic/Baltic Centre of Advanced Research on Ecosystem Services (effects of harvesting on soil, water and biodiversity);
- Collaboration with METLA (Finland) and Skogforsk (Sweden) on long-term experiments;
- Collaboration with University of Copenhagen on harvesting effects on soil nutrients and guidelines for soil sustainability.

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

Main achievements 2012

- The partial equilibrium models NTMII, EFI-GTM and NorFor have been improved regarding data and model structures[41].
- The results of an investigation on how increased demand for bioenergy will impact the wood biomass prices in Norway have been reported[42].
- A study was carried out on the economic analysis of the potential contribution of forest biomass to the EU RES target and its implications for the EU forest industries. The results are being published in a peer-reviewed journal[43].
- The impacts of agent information assumptions in forest sector modeling are still being investigated. Previous results were published in a peer-reviewed journal[44].

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[41] Erik Trømborg and Hanne K. Sjølie; *Data applied in the forest sector models NorFor and NTMIII*; INA fagrapport 17 (2011), Dept. of Ecology and Natural Resource Management, UMB

[42] Erik Trømborg, Torjus Folsland Bolkesjø, Even Bergseng og Per Kristian Rørstad; *Bærekraftig biodrivstoff til silvil luftfart i Norge – Biomassetilgang fra landbaserte ressurser*; UMB, Report for Avinor, October 2012

[43] Solberg, B.; *Impacts of EU RES policy on wood fibre supply and European forest industries*; in press, 2012

[44] Sjølie H. K., Latta G. S., Adams D. M., Solberg B.; *Impacts of agent information assumptions in forest sector modelling*; Journal of Forest Economics, 2011. 17(2): p. 169-184

- A peer-reviewed paper[45] was published on comparative analyses of costs of pellets production in Austria, Finland, Sweden, Germany, USA and Norway.

- Following the previously published peer-reviewed paper[46], the work continues on the greenhouse gas emission impacts of using Norwegian wood pellets.

- An overview of the policy instruments used in various European countries for promoting bioenergy was published in the Norwegian media[47].

- WP4.3 has contributed to the European Forest Sector Outlook Study II[48] (EFSOS II) lead by FAO and the UN Economic Commission for Europe, which every 10 year assemble the best research groups in Europe for such analyses. WP4.3's contribution was mainly on analyzing trade data (UN COMTRADE) and applying the bio-economic forest sector model EFI-GTM. A special report on this work will be published by UNECE/FAO in 2013.

Expectations for next 3-4 years

Starting from 2013, the main focus of WP4.3 will be on timber supply analyses, improved forest sector modeling, value chain analyses, and study of the impacts of policy instruments – with particular emphasis on the international wood markets.

- The timber supply analyses will be linked to the newly started EU project COOL, in which INA participates.

- The forest sector model improvements will consist of:
  - Including albedo impacts in the NorFor model (preliminary analyses done in WP4.1 indicates that albedo may be an important factor regarding GHG impacts of increased harvest in Norway),
  - Including the coal and gas sectors in the energy submodel in EFI-GTM (to better model the competition for wood biomass between the traditional forest industries, and CH and CHP plants);
  - Including full GHG accounting in the EFI-GTM.

- Regarding value chain analyses, we will participate in the cost studies and in applying the value chain results in NorFor.

- Regarding policy analyses we will focus particularly on the EU policies and their impacts on the international (and Norwegian) wood biomass markets.

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[45] Trømborg, Solberg; *Comparative analyses of costs of pellets production in Austria, Finland, Sweden, Germany, USA and Norway*; Biomass & Bioenergy, 2012, in press

[46] Sjølie H. K., Solberg B.; *Greenhouse gas emission impacts of use of Norwegian wood pellets: a sensitivity analysis*; Environmental Science and Policy, 2011. 14: p. 1028-1040

[47] Rørstad P. K., Solberg B.; *Er det nok råstoff til å nå bioenergimålene i Europa*, Norsk Skogbruk 9, pp. 30-31

[48] *European Forest Sector Outlook Study II*, UNECE, *http://www.unece.org/efsos2.html*

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SP5 Knowledge Transfer and Innovation

Figure 42: WBS of SP5.

Anders Hammer Strømman
Leader of Knowledge Transfer and Innovation
(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.

WP5.1 Bio-Energy Graduate School

One of the major tasks for the Bio-Energy Graduate School is to promote studies in bioenergy. Now both UMB and NTNU are running master courses in bioenergy on a regular basis based on an initiative from CenBio, as described in the Appendices. 4 master students performed their Master Thesis within CenBio activities in 2012 (see Table 12).

Approximately 30 PhD candidates have been affiliated with CenBio (see Table 10 and Table 11), though so far, PhD courses in bioenergy have not been developed. The CenBio Graduate School workshop was arranged on 18 January 2012 at UMB, focusing on climate impact from bioenergy. An initiative is now taken to develop this further into a PhD course on assessment of environmental impacts from bioenergy. This will be an international PhD course at NTNU which will be run first time in 2013.

In collaboration with The Norwegian Research School of Renewable Energy (NorRen) a summer school at PhD level was arranged in 2012 where bioenergy was one of the issues.

WP5.2 Knowledge transfer and dissemination

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 23) shows the deliverables that were finalized in 2012.

The deliverables are numbered according to the WP to which it belongs, with the third digit as a unique counter. One deliverable in a series of several planned deliverables is marked with a new counter as the fourth digit.

D0.1.4_4 where 0.1 refers to WP0.1, 4 is selected as the unique number for annual reports while the _4 means the third in a series; i.e. annual report for the third year of operation.

One of the overall targets for CenBio is to deliver 150 **international publications**, of which 75 in reputed peer-reviewed journals. Figure 43 and Figure 44 show the current status. The list of journal publications from 2012 is given in the Appendices (see Table 16).

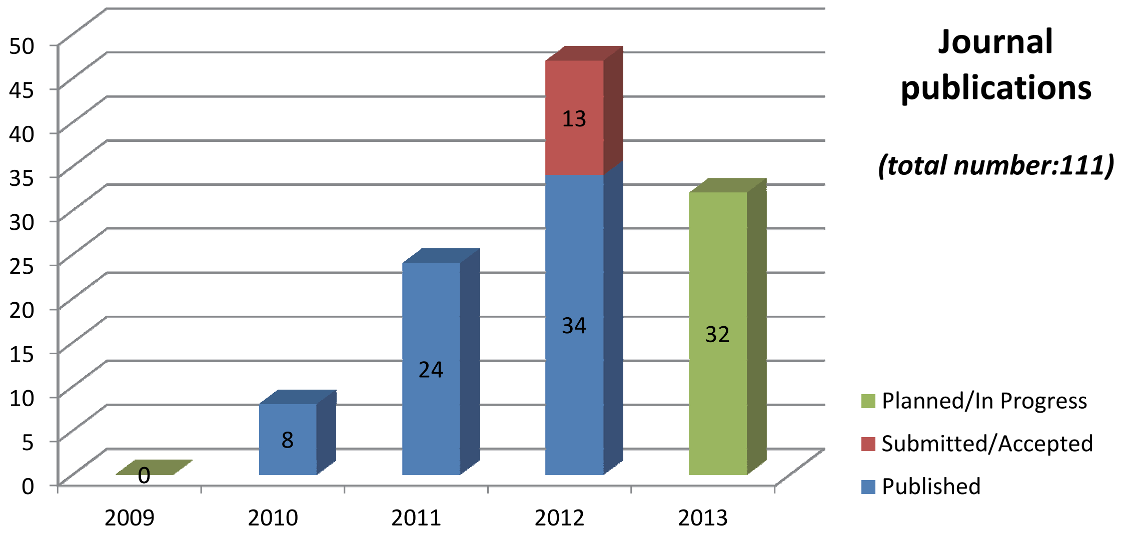

Figure 43: Status of peer-reviewed articles (per 2012-12-12).

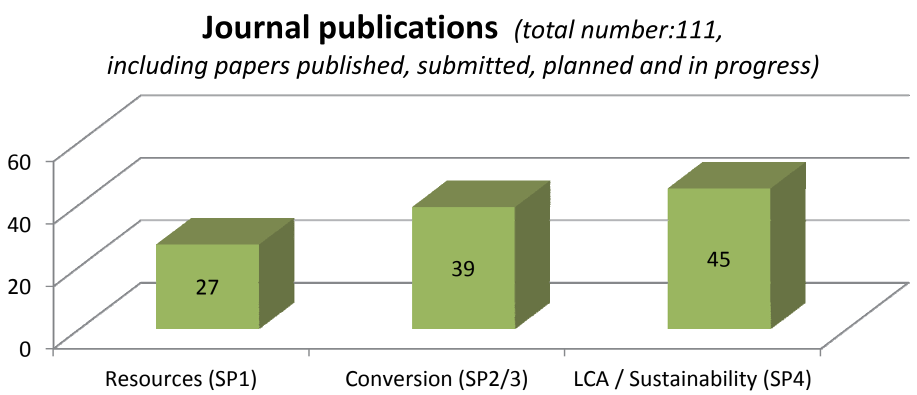

Figure 44: Status of peer-reviewed articles per research area (per 2012-12-12).

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In 2012, a large number of **international conferences** have been attended by the CenBio participants, as shown in the lists of conference papers and conference presentations in the Appendices (see Table 17 and Table 18).

CenBio researchers also appeared in the media, mainly in Norwegian newspapers, to sensibilize the population on some topical issues (wood stoves, biomass resources, etc.) or simply to popularize the topics of research tackled in CenBio. The list of **media contributions** is given in the Appendices (see Table 21).

Booklet - Best of CenBio

After four years of research activities, a few examples of stories involving successful collaborations between CenBio research scientists and user partners have been gathered in a booklet. The booklet is addressed to the user partners and the public at large, to reveal in an understandable manner some of the outstanding achievements from the Centre.

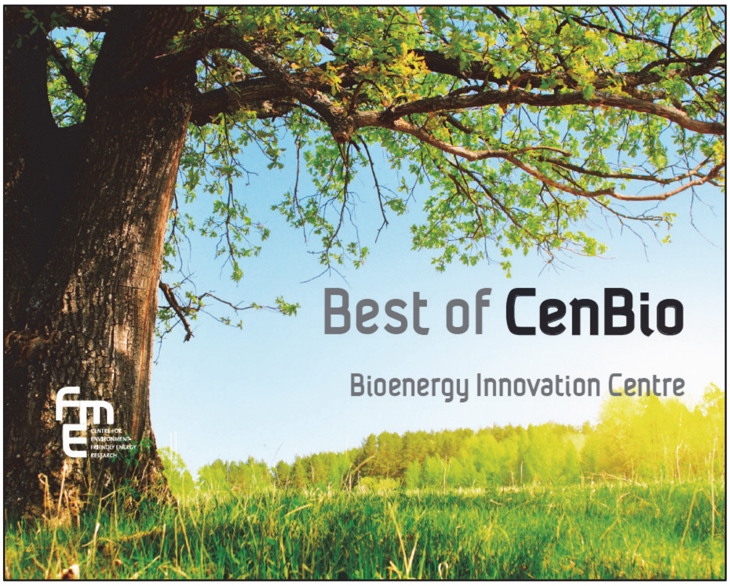

Figure 45: Booklet cover – Best of CenBio.

Five stories are given in the booklet, as follows:

1. Doctoral study at NFLI financed by the CenBio program and co-supervised by the Swedish Skogforsk, investigating the technologies for extracting small trees and lower the cost of harvesting the first thinning of forests.

2. Collaboration between SINTEF-ER research scientists and Granit Kleber to help them design and set up afterburners in their wood stoves in order to reduce the particle emissions and satisfy the Norwegian and European requirements.

3. Synergy with Cambi AS to develop efficient processes to generate biogas from cellulose-rich materials, such as birchwood, willow and straw.

4. CenBio co-financed work on upgrading biomass material for combustion through torrefaction processes with the KMB STOP project taking place at SINTEF Energy Research.

5. Internationally re-known work from NTNU Industrial Ecology financed by CenBio, on new methods to account for climate impact of forest harvesting.

Website: www.CenBio.no

The first version of the CenBio website was established and published in June 2009. The homepage is shown in Figure 46. The website is regularly updated, especially with new public deliverables and news relevant to the Centre.

Publications, including peer-reviewed journal papers, conference papers, conference presentations, chapters in book and media contribution are listed on the website. Web links have been implemented when the documents are publicly available online.

Figure 46: CenBio homepage - www.CenBio.no (2013-02-22).

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WP5.3 Innovation Management

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 two innovation workshops, which were arranged in 2010 and 2011. 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 5) includes more than 30 potential innovations that are identified by now, and we are working systematically to develop these. In this context, patenting and publishing processes are an important issue that has been considered in a separate deliverable.

Six innovations have so far been completed and fully implemented:

- Afterburner for woodstoves meeting the Norwegian environmental requirements, in close collaboration with the user partner Granit Kleber AS.
- New test method for wood stoves. It is time-saving (25-50%) compared to existing methods and also cost-saving. This is highly relevant for the wood stoves user partners such as Jøtul AS.
- 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 utilization as a commercial product 1: Special sand designed to give no germination of weeds, licensed to Asak Miljøstein AS.
- Ash utilization as a commercial product 2: Soil mixture for urban greening, licenced to Herremyr Gård AS, based on ash from the user partner Akershus Energi AS.

Table 5: List of innovations within CenBio (per 12 December 2012).

No	*Title*	*RTD partner*	*Category of innovation*	*Status*
I1.1.1	Biomass equations for Birch in Norway	NFLI	Model	*In progress*
I1.1.2	Biomass expansion factors for Spruce, Pine and Birch in Norway	NFLI	Model	*In progress*
I1.2.1	Cost efficient harvesting and transportation	NFLI	Technology	*In progress*
I1.2.2	Improved timbertrucks	NFLI	Technology	*In progress*
I1.2.3	Improved grapple	NFLI	Technology	*In progress*
I1.2.4	Improved bucking procedures	NFLI	Product	*Not started*
I1.3.1	Tailored fuel mixtures	SINTEF-ER	Product	*In progress*
I1.3.2	Tailored chip deliveries	NFLI	Concept	*In progress*
I1.4.1	New fertilizers	BIOFORSK	Product	*In progress*

I1.4.2	Organic NKP fertilizer	BIOFORSK	Product	*In progress*
I1.4.3	**Special sand**	**BIOFORSK**	**Product**	***Completed***
I1.4.4	**Soil mixture**	**BIOFORSK**	**Product**	***Completed***
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*
I2.2.1	CV-measurement	SINTEF-ER	Technology	*In progress*
I2.3.1	Biocarbon production	SINTEF-ER	Process	*In progress*
I2.4.1	Increased energy yields from anaerobic digestion	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 Granit 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	*In progress*
I3.2.2	Fossil C measurements	SINTEF-ER	Technology	*In progress*
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 CO_2 emissions from biomass (GWP bio)**	**NTNU**	**Model**	***Completed***
I4.2.1	Recommendations for sustainable harvesting	NFLI	New application	*In progress*
I4.2.2	Contribution to development of international standards	NFLI	New application	*In progress*
I4.2.3	Environmental performance for biomass value chains	NFLI	New application	*In progress*
I4.2.4	Criteria and Indicators for sustainable bioenergy	NFLI	New application	*In progress*
I4.3.1	Scenarios for market and cost development			

CenBio has introduced the “Bioenergy Innovation Award” (BIA), a national innovation award within stationary bioenergy. This award was established to stimulate and reward knowledge-based innovation and entrepreneurship. The Bioenergy Innovation Award 2012 was announced nationally and was awarded 18 January 2012 to Cambi AS, one of the CenBio partners, for their innovative biogas production process for biomass from waste and sewerage that is implemented in many plants world-wide.

Solør Bioenergi was the winner of the Bioenergy Innovation Award 2013, awarded on 11 April 2013, during the CenBio Days 2013, in Trondheim. Solør Bioenergi has succeeded in exploiting new possibilities to develop profitable activities, which has made them one of Norway's leading operators within the field of bioenergy. The winner has demonstrated that it is possible to establish and operate biomass-based CHP plants in Norway in a cost-effective manner, by recognizing and optimally exploiting synergy effects in the market. The company sets an example for others who want to establish biomass-based CHP plants in Norway.

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Figure 47: A plant from Solør Bioenergi, the winner of the Bioenergy Innovation Award 2013. This plant processes impregnated wood waste to produce energy. (photo: SINTEF)

FME CenSes has been actively involved in the CenBio Innovation workshops, a fruitful cooperation that has been extended in 2012. Based on the results from a CenSes master thesis, the emphasis on how to increase the value-creation for the user partners, based on CenBio results, has been intensified.

SP1 - Biomass supply and residue utilization

Participants have been very active on the international scene. A large biomass-based INTERREG project was carried out with Sweden (SLU) and Finland (METLA). Another FP7 project proposal was developed by participants of SP1 together with 8 EU countries. A second proposal is currently under development together with colleagues from SLU (Swedish University of Agricultural Sciences).

Cross-funding of activities in the Nordic Energy Fund (NEF) sponsored ENERWOODS project, (which includes Norway, Sweden, Finland, Latvia and Estonia), have led to significant cooperation with some of the leading institutes in the Nordic setting. The synergy from tasks defined in that project have allowed for comparative studies and experiences to be shared across borders. This flagship project is the first forest based project funded by the NEF and forms part of their strategic focus area 'Sustainable Energy Systems 2050'.

SP1 participants play a central role in COST (e.g. FP0902 Development and harmonization of new operational research and assessment procedures for sustainable forest biomass supply).

SP1 participants have been active in numerous International Energy Agency (IEA) tasks (e.g. Task 43 - Biomass feedstocks for energy markets) over the past triennium, where there has been good overlap between CenBio activity and the IEA focus. A number of these will go forward into the next triennium beginning in 2013.

The Nordic Council of Ministers (SNS) sponsors a number of "Centres of Advanced Research – CARs" as network organizations for promoting cooperation across the Nordic/Baltic region. Two doctor fellowships of direct relevance were carried out within the period of evaluation. Both utilized the strong Nordic network with regards to supervision and evaluation. This has subsequently resulted in a formalized cooperation with Skogforsk (Sweden) in developing simulation modules for a common focus on supply chain modeling (WP1.2).

SP2 - Conversion mechanisms

SP2 participants have actively contributed to a number of IEA tasks, including hosting meetings in Norway. Those tasks are related to biomass combustion and co-firing (Task 32), thermal gasification of biomass (Task 33) and energy from biogas and landfill gas (Task 37).

SP2, and SP3, researchers are also involved in the Joint Programme on Bioenergy from the European Energy Research Alliance (EERA) with over 25 members and the Biomass Technology Panel of the Renewable Heating and Cooling (RHC) European technology platform.

The collaboration with Åbo Akademi in Finland has been successfully running within WP2.1 and the work on additives.

SP2 participants have collaborated with Hawaii University, especially with Michael J. Antal, Jr. (one week/year in Trondheim) and visiting students for laboratory cooperation about bio-charcoal (WP2.3). CenBio's efforts within anaerobic digestion (WP2.4) have been further strengthened by an extensive collaboration with acclaimed and internationally active research groups, particularly at the Swedish University of Agricultural Sciences, the Swedish Institute of Agricultural and Environmental Engineering, and Aalborg University (DK).

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Within the frame of the KMB STOP project (WP2.5), a Dutch student from Twente University has carried out laboratory experiments on torrefaction as a part of his Master studies.

The work on gasification of torrefied materials (WP2.5) also induced a fruitful collaboration with the Catalonian Institute for Energy Research (IREC).

SP3 - Conversion technologies and emissions

SP3 participants are actively involved in standardization work (WG5 in CEN TC 295) related to testing methods for type approval of wood stoves. They are also involved in an EU project (EN-PME-TEST) with the goal of developing a common method for measuring particle emissions from wood stoves.

SP3 participants have taken part in IEA Task 32 dealing with biomass combustion and co-firing, and IEA Task 36 dealing with integrating energy recovery into solid waste management systems. In both SP2 and SP3, a close collaboration with Sandia National Laboratories and Stanford in the US on combustion and gasification related issues, is very valuable.

SP3 also participates actively in Prewin (European industrial network for Waste to Energy, WtE) through WP3.2.

SP4 - Sustainability analysis

Throughout CenBio, SP4 participants have built up a strong international cooperation with the Oregon State University (USA), European Forest Institute, the Finnish Forest Institute (METLA), the German Federal Forest Research Institute, the University of Lappenraanta (Finland), the University of Freiburg (Germany), the University of Minnesota (USA) and the University of North Carolina (USA).

SP4 researchers also actively participated to IEA tasks dealing with greenhouse gas balances of biomass and bioenergy systems (Task 38), and sustainable international bioenergy trade to secure supply and demand (Task 40).

Through SP4, CenBio has played an important role for providing new research projects, particularly EU financed ones, such as FORMIT (educational programme for science and research) and COOL (COmpeting uses Of forest Land). WP4.3 participants have contributed to the European Forest Sector Outlook Study II (EFSOS II), led by FAO and the UN Economic Commission for Europe, mainly about analysing trade data (UN COMTRADE) and applying the bio-economic forest sector model EFI-GTM. A special report on this work will be published by UNECE/FAO in 2013.

Supplementary facts on national and international cooperations have already been mentioned above, in the description of the activities for each SP and WP.

Participation in Tasks from the International Energy Agency (IEA)

Various IEA Bioenergy tasks with involvement of CenBio staff are listed in Table 6

Table 6: Participation in IEA Bioenergy activities.

IEA Bioenergy Task #	Task title	Task member WP #	Representative
Task 32	*Biomass Combustion and Co-firing*	02 SINTEF-ER WP2.1	Øyvind Skreiberg
Task 33	*Thermal Gasification of Biomass*	02 SINTEF-ER WP2.2	Roger A. Khalil
Task 36	*Integrating Energy Recovery into Solid Waste Management Systems*	02 SINTEF-ER WP3.2	Michaël Becidan
Task 37	*Energy from biogas and landfill gas*	04 BIOFORSK WP2.4	Espen Govasmark
Task 38	*Greenhouse gas balances of biomass and bioenergy systems*	01 UMB+03 NTNU SP4	Anders Strømman
Task 40	*Sustainable International Bioenergy Trade - Securing Supply and Demand*	01 UMB WP4.3	Birger Solberg Erik Trømborg
Task 43	*Biomass feedstocks for energy markets*	05 NFLI WP1.1	Simen Gjølsjø

International conferences

CenBio has been presented at a number of international conferences in 2012. Details are listed in Table 18.

International institutions

The international institutions listed below took part in collaborative research activities with CenBio in 2012:

- EFI – European Forest Institute
- University of Innsbruck (Austria)
- UFRN - Federal University of Rio Grande do Norte (Brazil)
- German Federal Forest Research Institute (D)
- University of Freiburg (D)
- Aalborg University (DK)
- Technical University of Denmark (DK)
- University of Copenhagen (DK)
- IREC - Catalonian Institute for Energy Research (ES)
- Åbo Akademi (FI)
- METLA - Finnish Forest Research Institute (FI)
- University of Lappenraanta (FI)
- Hungarian Academy of Sciences (Hungary)
- Skogforsk - Forestry Research Institute of Sweden (S)
- Swedish University of Agricultural Sciences (SLU) (S)

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- University of Belgrade (Serbia)
- Makerere University (Uganda)
- University of Hawaii at Manoa (USA)
- University of Minnesota (USA)
- University of North Carolina (USA)

The fruitful cooperation with Professor Michael J. Antal, Jr. from University of Hawaii has continued in 2012. The focus research area has been pyrolysis.

SINTEF Energy Research recruited the highly ranked, top-level scientist Alan Kerstein previously based at Sandia National Laboratories (California, USA) for a novel project within CenBio. He will be present at SINTEF Energy Research three months per year.

RECRUITMENT

The research within CenBio is mainly performed by permanent employees with the research institutes and the universities (see Table 7). In some cases, doctoral and postdoctoral researchers have been recruited to perform research within CenBio. A list of such researchers is given in Table 9, Table 10 and Table 11.

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APPENDICES

A. Personnel

Key Researchers

Table 7: Senior staff members who spent more than 10% of their time in CenBio in 2012.

Name	Affiliation	Univ. degree	Sex	Position within own organisation	% of full time
Odd Jarle Skjelhaugen	UMB	PhD	M	*Centre Director, Professor*	30%
Tron Haakon Eid	UMB	PhD	M	*Professor*	10%
Even Bergseng	UMB	PhD	M	*Research Scientist*	15%
Svein Jarle Horn	UMB	PhD	M	*Professor*	90%
Alexander Moiseyev	UMB	PhD	M	*Research Scientist*	100%
Marie Bysveen	SINTEF-ER	PhD	F	*Executive vice-president*	20%
Einar Jordanger	SINTEF-ER	PhD	M	*Quality- and Security Manager*	50%
Alexis Sevault	SINTEF-ER	PhD	M	*Research Scientist*	30%
Astrid Lilliestråle	SINTEF-ER	MSc	F	*Research Manager*	15%
Øyvind Skreiberg	SINTEF-ER	PhD	M	*Senior Research Scientist*	25%
Mette Bugge	SINTEF-ER	MSc	F	*Research Scientist*	20%
Edvard Karlsvik	SINTEF-ER	MSc	M	*Research Scientist (retired in October 2012)*	10%
Roger Khalil	SINTEF-ER	PhD	M	*Research Scientist*	20%
Michaël Becidan	SINTEF-ER	PhD	M	*Research Manager*	25%
Liang Wang	SINTEF-ER	PhD	M	*Research Scientist*	60%
Lars Sørum	SINTEF-ER	PhD	M	*President SINTEF Petroleum Research (from May 2012)*	10%
Anders H. Strømman	NTNU	PhD	M	*Professor*	10%
Francesco Cherubini	NTNU	PhD	M	*Research Scientist*	100%
Ottar Michelsen	NTNU	PhD	M	*Research Scientist*	30%
Trond Haraldsen	Bioforsk	PhD	M	*Senior Research Scientist*	25%
Uno Andersen	Bioforsk	MSc	M	*Research Scientist*	10%
Nicholas Clarke	NFLI	PhD	M	*Senior Research Scientist*	10%
Leif Kjøstelsen	NFLI	MSc	M	*Research Scientist*	10%
Helmer Belbo	NFLI	PhD	M	*Research Scientist*	20%
Eirik Nordhagen	NFLI	MSc	M	*Research Scientist*	10%
Anders M. E. Hohle	NFLI	MSc	M	*Research Scientist*	10%
Simen Gjølsjø	NFLI	MSc	M	*Senior Adviser*	20%
Rasmus Astrup	NFLI	PhD	M	*Research Director*	20%
Bruce Talbot	NFLI	PhD	M	*Research Scientist*	20%
Bjarte Arne Øye	SINTEF	PhD	M	*Research Scientist*	20%
Tomas Leffler	VRD	MSc	M	*PhD candidate*	10%
Åsa Astervik	VRD	MSc	F	*Research Scientist*	10%

Visiting Researchers

Table 8: Visiting senior researchers from other countries in 2012.

Name	Position	Organization	Country	Duration of stay
Michael J. Antal, Jr.	*Professor*	University of Hawaii at Manoa	USA	1 week/yr
Alan Kerstein	*Independent Research Scientist*	Former Sandia National Laboratories	USA	3 months/yr 2012-2014

Postdoctoral researchers

Table 9: List of postdoctoral researchers working in the Centre in 2012.

Name	Affiliation	Source of funding	Sex	Nationality	Period worked in the Centre
Xiaoke Ku	NTNU	CenBio	M	*Chinese*	2012 – 2013
Marit Lie	UMB	UMB	F	*Norwegian*	2010 – 2012
Bjørge Westereng	UMB	UMB	M	*Norwegian*	2010 – 2012
Zehra Zengin	UMB	UMB	F	*Turkish*	2010 – 2012

PhD students

A database on PhD students working on issues related to CenBio's research activities has been established; see Table 10 and Table 11.

Table 10: PhD students, both CenBio-funded and associated.

Name	Sex	Affiliation	Topic/Research area	Source of funding	Period in the Centre
Paulo Borges	M	UMB	*Develop decision support systems for long-term analyses of biomass*	CenBio WP1.1	2010-11 2013-11
Geoffrey Guest	M	NTNU	*Hybrid life cycle analysis of solid bio-fuel systems*	CenBio WP4.1	2009-08 2012-09
Dmitry Lysenko	M	NTNU	*Combustion modelling*	CenBio WP2.1	2010-03 2014-03
Dhruv Tapasvi	M	NTNU	*Experimental studies on biomass torrefaction and gasification*	CenBio WP2.3	2010-01 2013-01
Aaron Smith	M	UMB/ NFLI	*Develop models and methods for quantification of birch biomass*	CenBio WP1.1/ RCN	2010-08 2014-07
Eva Brod	F	UMB/ Bioforsk	*Organic waste resources and wood ash as fertiliser, phosphorus flows and stocks in the food system*	50% CenBio / RCN	2012-05 2016-04
Quang Vu Bach	M	NTNU	*Thermal pre-treatment of biomass and biomass residues*	20% CenBio / STOP	2011-08 2014-08
Silje Skår	F	UMB	*Ecological modelling related to increased biomass removal in forests in Norway*	25% CenBio / RCN	2009-12 2013-12
Ehsan Houshfar	M	NTNU	*Experimental studies on two-stage combustion of biomass*	CenBio In-kind KRAV	2009-03 2012-02
Shuling Chen Lillemo	F	UMB	*Bioenergy market*	RCN	2008-08 2013-06
Maria M. Estevez	F	UMB	*Optimization of biogas production (From biomass to biogas project)*	RCN	2009-12 2012-11
Kristian Fjørtoft	M	UMB	*Biogas optimization in farm scale biogas plants*	UMB	2009-08 2012-07
Zarah Forsberg	F	UMB	*Characterization and directed evolution of carbohydrate-binding modules (CBMs) for biomass conversion*	RCN	2010-01 2013-12
Geir Skjervak	M	03 NTNU (/Statoil)	*High Temperature Filtration of biomass combustion and gasification processes*	STATOIL/ own funding	2006 2013

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Table 11: Completed PhD theses linked to the Centre, up to 2012.

Name	Sex	Title of thesis	Adviser	Institution granting degree
Hanne K. Sjølie	F	*Analyses of the use of the Norwegian forest sector in climate change mitigation*	Birger Solberg	UMB
Tore S. Filbakk	M	*Fuel quality of forest biomass intended for chips and pellets: the influence of raw material characteristics, storage and handling*	Olav Høibø	UMB
Ryan Bright	M	*LCA of Second Generation Biofuels*	Anders H. Strømman	NTNU
Dhandapani Kannan	M	*Study of Second Generation Biofuels in Internal Combustion Engines*	Johan E. Hustad	NTNU
Kavitha Pathmanathan	F	*Granular-bed Filtration Assisted by Filter Cake Formation: Advanced Design and Experimental Verification*	Johan E. Hustad	NTNU
Ehsan Houshfar	M	*Experimental and numerical studies on two-stage combustion of biomass*	Terese Løvås	NTNU
Helmer Belbo	M	*Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees*	Rolf Björheden	Linnaeus University, Sweden

Master degrees

Both NTNU and UMB were providing courses on Bioenergy at Master level in 2012. Some details about the master's level courses in place in 2012 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:	40 in 2012
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:	**UMB – FORN310: Bioenergy – Resources, Profitability and Solutions**
Level:	Master, 5.0 credits
Objective:	The course should provide an in-depth understanding of the economics of bioenergy use and impacts on the carbon cycle and climate of bioenergy production. In addition, the course should provide insights in technologies for bioenergy production.
Frequency:	Annually, next in spring 2013. *No course in 2012 due to re-organization of study program.*
Students:	30 maximum
Activities:	Class lectures with sets of home exercises, combined with independent study.

Course:	UMB – 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 UMB and other Nordic forest research institutes.
Frequency:	Even years, autumn 2012.
Students:	5 took the exam in 2012, up to 30 can attend the next occurrence in 2014
Activities:	Short lectures to introduce the students to natural and socio-economic conditions for forest management in Norway and the other Nordic countries. Research papers within seven general topics, where INA contributes actively to forest research, are discussed in seminars with the teachers.

Table 12: M.Sc. theses in the Centre in 2012.

Name	Sex	Title of thesis	Adviser	Institution
Knut Ole Viken	M	*Biomass equations and biomass expansion factors (BEFs) for pine (pinus spp), spruce (picea spp.) and broadleaved dominated stands in Norway*	Tron Eid	UMB
Anne-Marit Melbye	F	*Life Cycle Assessment of Norwegian Bioenergy Heat and Power Systems*	Anders H. Strømman	NTNU
Moritz-Matthias Kayser	M	*On the application of hydrothermal processing for plant biomass pretreatment*	Khanh-Quang Tran	NTNU
Linn-Mari V. Høgalmen	F	*Optimalisering av et biogassanlegg (Optimisation of a biogas plant)*	Kjell Kolsaker	NTNU

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B. Accountancy

A detailed accounts report for 2012 was submitted to RCN in January 2013. The main financial figures are repeated in this annual report.

Budget

Table 13 shows the anticipated overall budget for CenBio over eight years. The total costs are estimated at NOK 265.026 million, distributed as given in the table.

The total funding from RCN is NOK 120 million for the project period, i.e. NOK 15 million per year. Since CenBio started 1 March 2009, the budget for 2009 was somewhat reduced compared to an average year. The cost budget for 2012 was NOK 34.722 million, while the estimate before final reporting for 2012 was NOK 38.012 million.

Table 13: CenBio overall budget.

		Actual	***Actual***	***Actual***	***Actual***	***Budget***	***Plan***			
Mill. NOK	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Total	**265.026**	27.738	38.594	39.291	38.012	31.300	28.800	28.800	28.800	3.691

Accounts 2012

Total costs reported from the partners in 2012 amounts to NOK 38.0 million, of which NOK 32.3 million from Research partners and NOK 5.7 million from corporate partners. The funding from RCN amounts to 39% of the total costs.

Funding

Table 14: Funding from various sources 2012.

Source	***NOK million***
The Research Council	15.000
Research partners	11.594
Industry partners	11.418
Public partners	0.000
Total	**38.012**

Costs

Table 15: Reported costs from various partners 2012.

Type	***NOK million***
Research partners	32.286
Industry partners	5.726
Public partners	0
Equipment	0
Total	**38.012**

C. Publications

All types of publications produced within CenBio in 2012 are listed in Table 23. Below some specific publications are listed in separate tables.

Journal Papers

Table 16: List of journal papers produced in 2012.

Title	Author(s)	Lead partner(s)	Journal
Adjacency constraints in forest planning - applying simulated annealing using different methods for the neighborhood search	Paulo Borges, Tron Eid, Even Bergseng	UMB, NFLI	*European Journal of Operational Research*
Small area estimation of forest attributes in the Norwegian National Forest Inventory	Johannes Breidenbach, Rasmus Astrup	NFLI	*European Journal of Forest Research*
An assessment of woody biomass in Norway: Total availability and harvest residue cost-supply curves	Rasmus Astrup; Tron Eid; Clara Antón-Fernández; Øivind Løken; Gunnhild Søgaard;	Norwegian Forest and Landscape Institute	*Biomass and Bioenergy*
Harvest residue potential in Norway – a bio-economic model appraisal	Even Bergseng, Tron Eid, Øivind Løken and Rasmus Astrup	UMB, NFLI	*Scandinavian Journal of Forest Research*
A simulation approach to determine the potential Efficiency in multi-tree felling and processing	Helmer Belbo	NFLI	
Fertilization effects of organic waste resources and bottom wood ash: results from a pot experiment	Eva Brod, Trond Knapp Haraldsen, Tor Arvid Breland	Bioforsk	*Agricultural and Food Science*
Influence of additives from wastes on biomass ash sintering tendency	Liang Wang, Geir Skjevrak, Johan E. Hustad, Øyvind Skreiberg	NTNU, SINTEF Energy Research	*Energy & Fuels*
Large-eddy simulation of the flow over a circular cylinder at Reynolds number 3900 using the OpenFOAM toolbox	Dmitry A. Lysenko, Ivar S. Ertesvåg, Kjell Erik Rian	NTNU	*Flow, Turbulence and Combustion*
Ash related behaviour in staged and non-staged combustion of biomass fuels and fuel mixtures	Becidan M., Todorovic D., Skreiberg Ø., Khalil R., Backman R., Goile F., Skreiberg A., Jovovic A. and Sørum L.	SINTEF Energy Research	*Biomass and Bioenergy*
A Critical Review on Additives to Reduce Ash Related Operation Problems in Biomass Combustion Applications	Liang Wang, Johan E. Hustad, Øyvind Skreiberg, Geir Skjevrak, Morten G. Grønli.	NTNU, SINTEF Energy Research	*Energy Procedia*
Effects of additives on barley straw and husk ashes sintering characteristics	Liang Wang, Øyvind Skreiberg, Johan E. Hustad, Geir Skjevrak, Morten G. Grønli	NTNU, SINTEF Energy Research	*Energy Procedia*
Kinetics of Corncob Pyrolysis	Marta Trninić, Liang Wang, Gábor Várhegyi, Morten Grønli and Øyvind Skreiberg	NTNU, SINTEF Energy Research	*Energy & Fuels*
Impact of steam explosion on biogas production from rape straw in relation to changes in chemical composition	Vivekanand Vivekanand, Peter Ryden, Svein J. Horn, Henri S. Tapp, Nikolaus Wellner, Vincent G.H. Eijsink, Keith W. Waldron	UMB	*Bioresource Technology*

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Effect of different steam explosion conditions on methane potential and enzymatic saccharification of birch	Vivekanand Vivekanand, Elisabeth F. Olsen, Vincent G.H. Eijsink, Svein J. Horn	UMB	*Bioresource Technology*
Torrefaction of Norwegian spruce and birch – An experimental study using macro-TGA	Dhruv Tapasvi, Roger A. Khalil, Øyvind Skreiberg, Khanh-Quang Tran, Morten G. Grønli.	NTNU, SINTEF Energy Research	*Energy & Fuels*
The kinetic behavior of torrefied biomass in an oxidative environment	Dhruv Tapasvi, Roger Antoine Khalil, Gabor Varhegyi, Øyvind Skreiberg, Khanh-Quang Tran, and Morten G. Gronli	NTNU, SINTEF Energy Research	*Energy & Fuels*
Site-specific global warming potentials of biogenic CO_2 for bioenergy: contributions from carbon fluxes and albedo dynamics	Cherubini F., Bright R. M., Strømman A. H.	NTNU	*Environmental Research Letters*
Application of probability distributions to the modeling of biogenic CO_2 fluxes in LCA	Francesco Cherubini, Geoffrey Guest, Anders H. Strømman	NTNU	*Global Change Biology Bioenergy*
The role of forest residues in the accounting for the global warming potential of bioenergy	Guest G, Cherubini F, Strømman AH.	NTNU	*Global Change Biology Bioenergy*
Climate impact potential of utilizing forest residues for bioenergy in Norway	Geoffrey Guest, Francesco Cherubini and Anders Hammer Strømman	NTNU	*Mitigation and Adaptation Strategies for Global Change*
Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment	Bright, R.M., F. Cherubini, and A.H. Strømman	NTNU	*Environmental Impact Assessment Review*
A comment to "Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral": Important insights beyond greenhouse gas accounting	Ryan M. Bright, Francesco Cherubini, Rasmus Astrup, Neil Bird, Annette L. Cowie, Mark J. Ducey, Gregg Marland, Kim Pingoud, Ilkka Savolainen and Anders H. Strømman	NTNU	*Global Change Biology Bioenergy*
Comparative analyses of costs of pellets production in Austria, Finland, Sweden , Germany, US and Norway	Trømborg, Solberg	UMB	*Biomass & Bioenergy*
Influences of international forest policy processes on national forest policies in Finland, Norway and Sweden	Lindstad B. H., Solberg B.	UMB	*Scandinavian Journal of Forest Research*
Biodiversity protection and economics in long-term boreal forest management — A detailed case for the valuation of protection measures	Bergseng E., Ask J. A., Framstad E., Gobakken T., Solberg B., Hoen H. F.	UMB	*Forest Policy and Economics*

Published Conference Papers (including extended abstracts and posters)

Table 17: List of conference papers produced in 2012.

Title	Author(s)	Lead partner(s)	Conference
Wood ash as raw material for Portland cement	Bjarte Øye	SINTEF-MC	*Ash Utilisation 2012; Stockholm, Sweden, January 2012*
A kinetic study for torrefaction of Norwegian biomass fuels	D. Tapasvi, R. A. Khalil, G. Varhegyi, K.-Q. Tran, M. G. Grønli, Ø. Skreiberg	NTNU, SINTEF-ER	*Proceedings of 20th European Biomass Conference and Exhibition, 18-22 June 2012, Milan, Italy, pp. 1733-1738*
Dual-fuel cycles to increase the efficiency of WtE installations	Becidan M., Anantharaman R.	SINTEF-ER	*Chemical Engineering Transactions, 15th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction*

Conference Presentations

Table 18: List of conference presentations 2012.

Title	Author(s)	Lead partner(s)	Conference
Selecting between wood supply chains on the basis of economic performance and robustness	Helmer Belbo	NFLI	*COST FP 0902 Forest Energy Action, Lisbon meeting, 18 Sept. 2012*
Systemanalyse - forsyningskjeder for skogsbrensel	Helmer Belbo	NFLI	*BIOSTIGEN sluttkonferanse, Ørsta, 4 Oct. 2012*
Tørking av flis og flisvirke	Helmer Belbo	NFLI	*Energivirkeseminar Mære Landbruksskole, 12 Nov. 2012*
Halm som brensel, klippeaggregater, tørking av flis og fliskvalitet	Helmer Belbo	NFLI	*Innovasjon Norge Fagseminar Bioenergi, Verdal 15 March 2012*
Produksjon av flis til bioenergi - utstyr og metoder	Helmer Belbo	NFLI	*Agroteknikk 2012, Lillestrøm, 17 Nov. 2012*
Avvirkning av lauvskog og kulturlandskap	Helmer Belbo	NFLI	*BIOSTIGEN sluttkonferanse, Ørsta, 4 Oct. 2012*
Mekanisert hogst av skogsbrensel - Energivirketynning	Helmer Belbo	NFLI	*Natur og Næring, avslutningskonferanse, Oslo, 19 April 2012*
Produksjon av brensel	Simen Gjølsjø	NFLI	*SINTEF-seminar: Slik skal du fyre med ved, Oslo, 4 Dec. 2012*
Quality requirements for wood ash as K component in recycled NPK fertilizers	Trond Knapp Haraldsen, Eva Martina Brod, Tore Krogstad	BIOFORSK	*Ash Utilisation 2012; Stockholm, Sweden, January 2012*
Thermal degradation properties of torrefied fuel	Dhruv Tapasvi, Roger A. Khalil, Øyvind Skreiberg	NTNU, SINTEF-ER	*Renewable Energy Research Conference 2012, 16-17 April, Trondheim, Norway*
Modelling staged combustion of biomass with a reduced chemical kinetics mechanism: Fuel rich condition	Ehsan Houshfar, Øyvind Skreiberg, Terese Løvås	NTNU, SINTEF-ER	*34th Combustion Symposium work-in-progress poster, 29 July - 3 August 2012, Warzaw, Poland*
Is Elevated Pressure Required to Achieve a High Fixed-Carbon Yield of Charcoal From Biomass?	Liang Wang, Øyvind Skreiberg, Morten G. Grønli, Michael J. Antal Jr	NTNU, SINTEF-ER	*AIChE Annual Meeting in Pittsburgh, PA from 28 Oct. to 2 Nov. 2012*

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Additives for reduced corrosion and fouling in BtE - An experimental study	Liang Wang, Michael Becidan, Øyvind Skreiberg	SINTEF-ER	*3rd International Conference on Biomass and Waste Combustion, 24-25 April 2012, London*
Status på utviklingen av vedovner	Morten Seljeskog	SINTEF-ER	*SINTEF-seminar: Slik skal du fyre med ved, Oslo, 4 Dec. 2012*
Vedfyring i Bergen	Morten Seljeskog	SINTEF-ER	*Riktig vedfyring i riktig ildsted, Klimafestivalen, Bergen, 17 Oct. 2012*
Ny og lovende teknologi for akkumulering av varme fra vedovner	Morten Seljeskog	SINTEF-ER	*Bioenergidagene, Småskala bioenergiløsninger, Hamar, 6 Nov. 2012*
CenBio midtveis, Utvalgte resultater fra 2009-2012	Michael Becidan	SINTEF-ER	*AvfallNorge energiutnyttelsesseminar, Bergen, 12 Sept. 2012*
Dual-fuel cycles to increase the efficiency of WtE installations	Becidan M., Anantharaman R.	SINTEF-ER	*Chemical Engineering Transactions, 15th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction*
Oxygen enhanced combustion of biomass	Roger A. Khalil, Michaël Becidan, Øyvind Skreiberg	SINTEF-ER	*Renewable Energy Research Conference 2012, 16-17 April, Trondheim, Norway*
GWPs of biogenic CO_2 from bioenergy: contributions from timing of CO_2 fluxes and albedo	Francesco Cherubini, Ryan M. Bright, Anders Hammer Strømman	NTNU	*IEA Bioenergy Task 38 workshop on timing of emissions, Chicago (USA); 12-13 April 2012*
Modelling of biogenic CO_2 fluxes in LCA and their integration with the global C cycle.	Francesco Cherubini, Ryan M. Bright, Anders Hammer Strømman	NTNU	*SETAC Europe Conference, Berlin (Germany); 21-24 May 2012*
The Climate Impact Potential of Utilizing Forest Residues for Bioenergy—the case of Norwegian Spruce in Norway	Geoffrey Guest, Francesco Cherubini, Anders Hammer Strømman	NTNU	*Technoport, Trondheim, Norway*
Dual discounting in forest sector climate change mitigation	Hanne K. Sjølie, Greg Latta, Birger Solberg		*Forest Sector modeling workshop, Nancy, France, 31 May 2012*
Preliminary results from the Gaupen field experiment - changes in soil water chemistry after harvesting with and without removal of residues	Nicholas Clarke	NFLI	*Workshop on impacts of increased use of bioenergy – modelling and guidelines, Copenhagen, Denmark, 23-24 January 2012*
Oversiktsbilde bioenergiforskning Ås	Odd Jarle Skjelhaugen	UMB	*Bioenergidagene, Hamar, 6 Nov. 2012*
FoU-utfordringer i Bioenergiens verdikjeder	Odd Jarle Skjelhaugen	UMB	*Bioenergidagene, Hamar, 6 Nov. 2012*
Vedfyring i endring	Odd Jarle Skjelhaugen	UMB	*Vedfyring i et klima- og energipolitisk perspektiv , Oslo, 16 Oct. 2012*
Bioenergi i framtidens energisystem	Odd Jarle Skjelhaugen	UMB	*Oppstartseminar fornybar-energi-studenter UMB, Ås, 14 Aug. 2012*
Biogas Research and Opportunities	Odd Jarle Skjelhaugen	UMB	*Cambi Biogas summer seminar , Ås, 11 June 2012*
Bioenergiforskning i vekst	Odd Jarle Skjelhaugen	UMB	*Orientering til LMD, Oslo, 11 June 2012*
CREE + CenBio = Complete bioenergy value chain	Odd Jarle Skjelhaugen	UMB	*Orientering til FME-CREE, Oslo, 7 March 2012*
Wood ash as raw material for Portland cement	Bjarte Øye	SINTEF-MC	*Ash Utilisation 2012; Stockholm, Sweden, January 2012*

Chapters in books

Table 19: List of books with contributions from CenBio in 2012.

Title	Author(s)	Lead partner	Book title
Good practice guidelines for biomass production studies	Talbot Bruce	NFLI	*COST Action FP-0902 WG 2 Operations research and measurement methodologies*
Economic Sustainability of biomass feedstock supply	Talbot Bruce	NFLI	*IEA task 43 report*

Reports

Table 20: List of reports 2012.

Title	Author(s)	Lead partner	Class.
Annual Work Plan 2013	Einar Jordanger (+CMT)	SINTEF-ER	*Restricted*
Progress report 1 2012	Einar Jordanger	SINTEF-ER	*Restricted*
Progress report 2 2012	Einar Jordanger	SINTEF-ER	*Restricted*
Accounts report 2011	Einar Jordanger	SINTEF-ER	*Restricted*
Accounts report 2012	Einar Jordanger	SINTEF-ER	*Restricted*
Annual report 2011	Einar Jordanger, Michael Becidan, Svein Tønseth	SINTEF-ER	*Public*
Midterm evaluation report	CMT	SINTEF-ER	*Restricted*
Bundling woody roadside vegetation	Helmer Belbo, Leif Kjøstelsen	NFLI	*Public*
Network involved in supplying woody biomass for energy	Bruce Talbot	BIOFORSK	*Restricted*
Systems analysis of ten supply chains for wood fuel	Bruce Talbot?	NFLI	*Public*
Virkning av ulike blandinger av spirehemmende fugesand	Trond Knapp Haraldsen	BIOFORSK	*Restricted*
Bioenergy laboratory development 2012	Øyvind Skreiberg	SINTEF-ER	*Restricted*
Measurement campaign - Energos	Khalil R. A., Horrigmo W., Bugge M., Skreiberg Ø.	SINTEF-ER	*Restricted*
Comparison of forest management guidelines for sustainable harvesting of biomass for bioenergy	Tuyet Lan Phan, Nicholas Clarke	NFLI	*Public*
Effects of forest harvesting and slash removal on soil carbon stocks	Nicholas Clarke	NFLI	*Public*
Contribution to chapter 3 (Scenario analysis: reference future and policy choices) and chapter 5 (Main policy issues and challenges, in the light of the scenario analysis) of EFSOS II (The European Forest Sector Outlook Study II), UN, Geneva – ECE/TIM/SP/28)	Birger Solberg	UMB	*Public*
IEA Bioenergy task 40 – Country report 2011 for Norway	Erik Trømborg	UMB	*Public*
Communication plan	Odd Jarle Skjelhaugen	UMB	*Public*

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Media contributions

We have listed most of the contributions from CenBio personnel during 2012, mostly in Norwegian media, in Table 21.

Table 21: List of media contributions 2012.

Title	Author(s)	Lead partner(s)	Media
Biomasse kraft-varme (CHP) i Norge – Hvor står vi og hvor går vi?	Øyvind Skreiberg	SINTEF-ER	*Xergi*
Northern research	Cherubini F.	NTNU	*Enel TV [TV]*
Energy the Bio Way	Cherubini F.		*Control Engineering Asia [Avis]*
Den gode veien fra hogstavfall til bioenergi	Hanssen K.H.	NFLI	*forskning.no*
Økt hogst er gunstig for klimaet	Bårdsgård H.	NTNU	*Nationen.no*
Vegetasjon på skogbunnen	Dalen L. S., Økland T.	NFLI	*Skog og Landskap (website)*
Riktig lagring gir god kvalitet på biobrensel	Filbakk T.	NFLI	*Skog og Landskap (website)*
Bunting av heltre og hogstavfall	Belbo H.	NFLI	*Skog og Landskap (website)*
Så flisa fyker	Dalen L. S.	NFLI	*forskning.no*
Skogen kan gjøre mye av klimajobben	Brekk L. P.		*Dagens Næringsliv*
Mat for bybuss og åker	Solerød M. S.		*Forskningsrådet Renergi (website)*
Eksplosiv biogassforskning	Gulden K.T.	Bioforsk	*forskning.no*
Akershus EnergiPark hedret pa Rio+20 konferanse			*Akershus Energi (website)*
Optimistiske forskere pa biogasstreff	Gulden K.T.	Bioforsk	*Bioforsk (website)*
Fra nullverdi til bioenergi	Schärer J.	Bioforsk	*forskning.no*
Spørsmål om biodrivstoff til Anders H.Strømman	Grønli K.S.	NTNU	*Teknisk ukeblad*
Slutt på peiskosen	Sprenger M.		*Teknisk ukeblad*
Sintef sikrer forsker-ess	Stensvold T.	SINTEF-ER	*Teknisk ukeblad*
Nytt biogassanlegg i Drammen	Bjørndal J .		*Bioenergi*
Forbrenningseksperten sender stafettpinnen videre	Kløvstad A.	SINTEF-ER	*Bioenergi*
Nytt avfallsforbrenningsanlegg i tøft marked	Bjørndal J .		*Bioenergi*
Grenser for biomasseuttaket fra skogen	Bardalen A.	NFLI	*Bioenergi*
Seier i Renergi Grand Prix	Gulden K. T.	Bioforsk	*Bioforsk (website)*
Ved omsatt etter vekt kommer	Woxholtt S.	NFLI	*Skog og Landskap (website)*
Norge styrker forbrenningslandslaget	Tønseth S.	SINTEF-ER	*Xergi SINTEF Energi AS*
Gamle ovner må byttes ut	Tale Sundlisæter	SINTEF-ER	*Teknisk Ukeblad (Website)*

D. License Agreements

Table 22: License agreements established in 2012.

Title	WP	Responsible	Type	Status
"Blandingsresept for fugesand": special sand with ash for use in urban grey environments	WP1.4	Trond Knapp Haraldsen	Product - License agreement	*Signed (2012.10.01)*
"Jordprodukt: resepter for jordblandinger": soil mixture for urban greening using ash from Akershus	WP1.4	Trond Knapp Haraldsen	Product - License agreement	*Signed (2012.09.29)*

E. Deliverables List – Publications

AWP2012 included a total of ***87*** deliverables. Of these, ***84*** were planned to be finalized in 2012. ***19*** deliverables were delayed from 2011 and transferred in February 2012 to the operative Deliverables list for 2012. Hence a total of 103 deliverables were scheduled to be finalized in 2012.

During 2012, ***23*** new deliverables were added to the 2012 Deliverables list. Some partners have produced more publications and reports than planned. In some cases, new publications with co-funding from CenBio have been added to the list, and in other cases, a planned deliverable has been split into two deliverables, as for example, a presentation at a conference and the associated proceedings paper is counted as two deliverables.

The total number of deliverables in Table 23 below is therefore ***129***, with 126 deliverables due in 2012.

During the year, 35 deliverables were delayed for various reasons. Almost all delays can be explained by the following causes: (1) delayed recruitments, (2) work overload form researchers or use partners, (3) breakdown of instruments, and (4) delayed deliveries. The delayed deliverables have been transferred to the 2012 Deliverables list.

In total, ***91*** deliverables were finalized in 2012.

Table 23: List of Deliverables 2012.

Del. No	Deliverables title	Lead partner	Dated	New*
D0.1.1_5	*Annual Work Plan 2013*	SINTEF-ER	*2012.12.31*	
D0.1.2_41	*Progress report 1 2012*	SINTEF-ER	*2012.05.31*	
D0.1.2_42	*Progress report 2 2012*	SINTEF-ER	*2012.12.06*	
D0.1.3_3	*Accounts report 2011*	SINTEF-ER	*2012.02.06*	
D0.1.3_4	*Accounts report 2012*	SINTEF-ER	*2013.01.25*	
D0.1.4_3	*Annual report 2011*	SINTEF-ER	*2012.04.01*	
D0.1.5_1	*Midterm evaluation report*	SINTEF-ER	*2012.11.30*	
D1.1.4	*Harvest residue potential in Norway - a bio-economic model appraisal*	UMB	*2012.09.12*	
D1.1.7	*Potential future biomass availability in Norway (pop science article)*	UMB	*2012.09.30*	
D1.1.11	*Biomass equations and biomass expansion factors (BEFs) for pine (pinus spp), spruce (picea spp.) and broadleaved dominated stands in Norway*	UMB	*2012.06.15*	x
D1.1.12	*Biomass expansion factors*	NFLI	*Delayed*	

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D1.1.13	*Small area estimation of forest attributes in the Norwegian National Forest Inventory*	NFLI	*2012.01.03*	
D1.1.14	*Adjacency constraints in forest planning - applying simulated annealing using different methods for the neighborhood search*	UMB	*2012.09.26*	
D1.1.15	*Biomass mapping development – case Norway*	NFLI	*2012.01.03*	
D1.2.3	*Overview of Biomass Production and Delivery Systems*	NFLI	*2012.09.12*	x
D1.2.5	*Network involved in supplying woody biomass for energy*	NFLI	*2012.09.01*	n
D1.2.5_3	*Network involved in supplying woody biomass for energy*	NFLI	*Delayed*	n
D1.2.6	*Transport economic gains in new combi-truck concepts in an applied setting in Norway*	NFLI	*Delayed*	
D1.2.8	*A simulation approach to determine the potential efficiency in multi-tree felling and processing*	NFLI	*2012.09.10*	
D1.2.9	*Bunting av vegkantvirke. Produktivitet og økonomi*	NFLI	*2012.01.31*	x
D1.2.11	*Economic sustainability of biomass feedstock supply*	NFLI	*Delayed*	n
D1.2.12	*Systems analysis of ten supply chains for wood fuel*	NFLI	*2012.12.01*	n
D1.2.13	*Good practice guidelines for biomass production studies*	NFLI	*2012.10.15*	n
D1.3.3	*Data about selected waste fractions characteristics*	SINTEF-ER	*Cont.*	
D1.3.5	*Influence of biomass' location and soil type in combustion characteristics*	SINTEF-ER	*Delayed*	
D1.3.6	*Storage of whole trees and GROT*	NFLI	*2012.01.09*	
D1.3.7	*Wood chip quality database*	NFLI	*Delayed*	
D1.3.8	*Stem wood heating value and ash content of Norway spruce (Picea abies)*	NFLI/SINTEF-ER	*Delayed*	
D1.3.9	*Branch wood heating value and ash content of Norway spruce (Picea abies)*	NFLI/SINTEF-ER	*Delayed*	
D1.3.10	*Slagging properties of Northland forest trees*	NFLI/SINTEF-ER	*Delayed*	
D1.4.2	*Results from two greenhouse experiments with ash based products (experiments carried out in 2010 and 2011)*	BIOFORSK	*Delayed*	x
D1.4.4	*Efficiency of organic NPK fertilizers combining N-rich organic wastes and bottom wood ash*	BIOFORSK	*Delayed*	
D1.4.5	*Leaching of plant nutrients using waste based organic NPK fertilizers compared to mineral NPK fertilizers*	BIOFORSK	*Delayed*	
D1.4.6	*Virkning av ulike blandinger av spirehemmende fugesand*	BIOFORSK	*2012.06.15*	n
D1.4.7	*Selection of suitable ashes/residues coupled to relevant application*	SINTEF-MC	*Delayed*	
D1.4.8_3	*Fertilization effects of organic waste resources and bottom wood ash: results from a pot experiment*	Bioforsk	*2012.04.30*	
D1.4.9	*P availability in solid biogas residues*	Bioforsk	*Delayed*	
D2.1.8	*NOx emission reduction by staged combustion - modelling study*	SINTEF-ER	*Delayed*	
D2.1.10	*IEA Task 32 activity report*	SINTEF-ER	*2/year*	
D2.1.11	*Bioenergy laboratory development 2012*	SINTEF-ER	*2012.12.17*	
D2.1.12	*Additives and fuel mixes for reduced corrosion and fouling - Experimental study, phase 2*	SINTEF-ER	*Due 2013*	
D2.1.13_10	*Influence of additives from wastes on biomass ash sintering tendency*	NTNU	*2012.08.14*	n
D2.1.13_11	*Modeling of turbulent separated flows using OpenFOAM*	NTNU	*2012.01.22*	n
D2.1.13_12	*Large-eddy simulation of the flow over a circular cylinder at Reynolds number 3900 using the OpenFoam toolbox*	NTNU	*2012.12.01*	n
D2.1.13_13	*Sintering Characteristics of Sewage Sludge Ashes at Elevated Temperatures*	NTNU	*2012.09.25*	n
D2.1.13_14	*Sintering Characteristics and Mineral Transformation Behaviors of Corn Cob Ashes*	NTNU	*2012.09.25*	n

D2.1.13_15	*Thermal Characterization of Uganda's Acacia Hockii, Combretum Molle, Eucalyptus Grandis and Terminalia Glaucescens for Gasification*	NTNU	*2012.09.25*	n
D2.1.13_16	*Effects of Sewage Sludge and Marble Sludge Addition on Slag Characteristics during Wood Waste Pellets Combustion*	NTNU	*2012.09.25*	n
D2.2.11_5	*IEA Task 33 activity report 2013*	SINTEF-ER	*2/year*	
D2.2.12	*Literature review on syngas oxidation mechanisms*	Energos	*Delayed*	
D2.2.13	*Reduced syngas oxidation mechanisms*	Energos	*Delayed*	
D2.2.14	*Syngas formation: thermodynamic equilibrium calculations*	SINTEF-ER	*Delayed*	
D2.2.15	*Gasification modelling – Phase 1*	NTNU	*Delayed*	
D2.3.6	*Is elevated pressure required to achieve the theoretical fixed-carbon yield of charcoal from biomass? 2. (new fuels)*	SINTEF-ER	*2013.01.08*	
D2.3.7	*EERA activity report*	SINTEF-ER	*2012.12.30*	
D2.4.6	*IEA task 37 "Energy from biogas and landfill gas" Espen Govatsmark, Bioforsk. Minutes.*	BIOFORSK	*Cont.*	
D2.4.7	*Information flyer and PR*	BIOFORSK	*2012.10.24*	x
D2.4.9	*Effect of different steam explosion conditions on methane potential and enzymatic saccharification of birch*	UMB	*2012.10.24*	x
D2.4.11	*Effect of pretreatment on anaerobic digestion*	BIOFORSK	*Delayed*	x
D2.4.12	*Demonstration of anaerobic digestion of cow manure in 6 m 3 pilot reactor*	BIOFORSK	*Delayed*	x
D2.4.13	*Description of an expanded compositional analysis of CenBio relevant raw materials and key process fractions*	Bioforsk/UMB	*Delayed*	x
D2.4.14	*International seminar at Ås*	UMB	*2012.10.24*	
D2.4.15	*Peer reviewed scientific publication on pretreatment of grass*	UMB	*Delayed*	
D2.4.16	*Peer reviewed journal paper on fish waste in anaerobic digestion*	Bioforsk	*2012.12.30*	
D2.4.17	*MSc thesis on fish waste in anaerobic digestion*	Bioforsk	*2012.12.01*	
D2.4.18	*Impact of steam explosion on biogas production from rape straw in relation to changes in chemical composition*	UMB	*2012.11.01*	n
D2.5.1_1	*Torrefaction of Norwegian spruce and birch – An experimental study using macro-TGA*	SINTEF-ER	*2012.07.18*	n
D2.5.1_2	*The kinetic behavior of torrefied biomass in an oxidative environment*	SINTEF-ER	*2012.11.26*	n
D3.1.4	*Reports from standardization meetings*	SINTEF-ER	*x/year*	
D3.1.6	*Presentation of results from new equipment for measuring*	SINTEF-ER	*2013.01.28*	
D3.2.4	*Dual-fuel cycles to increase the efficiency of WtE installations*	SINTEF-ER	*2012.09.11*	
D3.2.6	*IEA Task 36 activity report*	SINTEF-ER	*2/year*	
D3.2.7	*PREWIN activity report*	SINTEF-ER	*2012.12.31*	
D3.2.8	*Collection of short literature review notes on unusual waste fractions*	SINTEF-ER	*2012.12.21*	
D3.2.9	*Fly ash from WtE*	SINTEF-ER	*2012.08.27*	
D3.2.10	*Oxygen Enhanced Combustion of Biomass*	SINTEF-ER	*2012.04.16*	
D3.2.11	*CenBio midtveis - Utvalgte resultater fra 2009-2012*	SINTEF-ER	*2012.09.12*	n
D3.2.12	*Dual-fuel cycles to increase the efficiency of WtE installations*	SINTEF-ER	*2012.08.25*	n
D3.3.4	*Optimisation to achieve minimum corrosion rate and maximum NOx and CO reduction*	VRD	*Delayed*	
D3.3.5	*Poptek article on CHP recommendations for Norway*	SINTEF-ER	*2012.12.31*	
D3.3.6	*Short term measurements 1 and 2*	VRD	*Delayed*	
D3.4.5	*Measurement campaign*	SINTEF-ER	*2012.11.30*	
D3.4.6	*Measurement campaign planning (Akershus Energi)*	SINTEF-ER	*Delayed*	

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D3.4.7	*NOx formation - Initial CFD study*	SINTEF-ER	*Delayed*	
D4.1.11	*Premises for biodiversity indicator design in LCA*	NTNU	*Delayed*	x
D4.1.21	*Chemicals from lignocellulosic biomass: opportunities, perspectives, and potential of biorefinery systems*	NTNU	*2012.09.20*	x
D4.1.28	*Climate impact of bioenergy systems: from single stand to landscape level*	NTNU	*Delayed*	
D4.1.29	*Global Warming Potential of biogenic CO_2 emissions from different bioenergy pathways*	NTNU	*2012.09.20*	
D4.1.30	*Application of probability distributions to the modeling of biogenic CO_2 fluxes in LCA*	NTNU	*2012.09.20*	
D4.1.31	*The role of forest residues in the accounting for the global warming potential of bioenergy*	NTNU	*2012.09.20*	
D.4.1.32	*Climate impact potential of utilizing forest residues for bioenergy in Norway*	NTNU	*2012.09.20*	
D.4.1.33_1	*Continent-wide response of mountain vegetation to climate change*	NTNU	*2012.01.10*	x
D.4.1.33_2	*Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment*	NTNU	*2012.11.01*	n
D.4.1.33_3	*A comment to "Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral": Important insights beyond greenhouse gas accounting*	NTNU	*2012.11.01*	n
D4.2.6	*Effects of different harvesting systems on soil fungi*	NFLI	*Delayed*	x
D4.2.8	*Ecological consequences of increased biomass removal for bioenergy from boreal forests*	NFLI	*2012.05.23*	
D4.2.9	*Comparison of forest management guidelines for sustainable harvesting of biomass for bioenergy*	NFLI	*2012.04.19*	
D4.2.10	*Effects of forest harvesting and slash removal on soil carbon stocks*	NFLI	*2012.02.06*	
D4.3.8	*Costs and production inputs of bioenergy production*	UMB	*Delayed*	x
D4.3.11	*Conceptual report on what is meant by sustainable bioenergy production, and discussion of corresponding criteria and indicators*	UMB	*Delayed*	x
D4.3.13-1 and 2	*Participation in EU-Bioenergy Network (Bionet) III meetings*	UMB	*2011.10.30*	
D4.3.14-2	*Participation in meeting in IEA Task 40 International trade of biomass. Country report for Norway*	UMB	*2011.12.30*	
D4.3.15	*Comparative analyses of costs of pellets production in Austria, Finland, Sweden, Germany, US and Norway*	UMB	*2012.11.20*	
D4.3.16	*Estimation of the carbon leakage effects of increased harvest in Norway*	UMB	*Delayed*	
D4.3.17	*Wood biomass availability in Europe ("Er det nok råstoff til å nå bioenergimålene i Europa?")*	UMB	*2011.09.30*	
D4.3.18	*Contribution to chapter 3 (Scenario analysis: reference future and policy choices) and chapter 5 (Main policy issues and challenges, in the light of the scenario analysis) of EFSOS II (The European Forest Sector Outlook Study II), UN, Geneva – ECE/TIM/SP/28)*	UMB	*2011.09.30*	
D4.3.19	*Presentation at IUFRO international conference on forest sector modelling, Nancy, May 20-23, 2012. Dual discounting in forest sector climate change mitigation*	UMB	*2012.05.30*	
D4.3.20	*Overview of policy instruments used in various European countries for promoting bioenergy ("Virkemidler for å fremme fornybar")*	UMB	*2011.09.30*	
D4.3.21_1	*Influences of international forest policy processes on national forest policies in Finland, Norway and Sweden*	UMB	*2012.02.01*	n
D4.3.21_2	*Biodiversity protection and economics in long-term boreal forest management — A detailed case for the valuation of protection measures*	UMB	*2012.02.01*	n

D5.1.8	*PhD seminar, CenBio graduate school*	NTNU	*2012.01.27*	
D5.1.8_4	*PhD workshop 2013, CenBio graduate school –*	NTNU	*Due 2013*	n
D5.1.9	*First version, plan for collaboration on PhD education*	NTNU	*2013.01.25*	x
D5.1.10	*Brochure on Bioenergy PhD courses at UMB and NTNU*	NTNU	*2013.01.25*	
D5.2.9	*1-3 business PhD applications*	UMB	*2012.11.25*	x
D5.2.15	*Other conferences, which to join, and in which way*	UMB	*2012.11.25*	x
D5.2.17	*Communication plan*	UMB	*2012.05.22*	
D5.2.18	*4 industry workshops*	SE	*2012.11.25*	
D5.2.19	*3 industry cases*	UMB	*Delayed*	
D5.2.20	*Scientific publishing* - *20 scientific papers submitted* - *10 conference papers*	UMB	*2012.11.29*	
D5.2.21	*CenBio website*	UMB + SINTEF-ER	*cont.*	
D5.2.22	*CenBio conference January 2013*	SINTEF-ER	*Due 2013*	
D5.2.23	*External conferences and presentations* *- 10 international conferences, seminars, workshops* *- 10 presentations*	SINTEF-ER	*2012.11.25*	
D5.2.24	*Popular publishing* *- 20 popular articles and press news*	UMB + all WPs	*2012.11.26*	
D5.3.4	*Publishing and patenting processes*	SINTEF-ER	*2012.08.30*	x
D5.3.8_2	*Status of CenBio Innovations, 2nd version*	SINTEF-ER	*2012.12.21*	
D5.3.10_2	*Extending the CenBio activities - Status*	SINTEF-ER	*2012.12.21*	
D5.3.11	*Award the 2nd Bioenergy Innovation Award*	SINTEF-ER	*2012.01.18*	
D5.3.12	*Third Innovation workshop*	SINTEF-ER	*Delayed*	

**: In the column "New", "n" stands for new deliverables, while "x" stands for transferred deliverables from 2011.*

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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 24.

Table 24: Short names of partners.

No	Short name	Entity legal name
01	UMB	Universitetet for miljø- og biovitenskap (Host institution)
02	SINTER-ER	SINTEF Energi AS (Coordinating institution)
03	NTNU	Norges teknisk-naturvitenskapelige universitet NTNU
04	BIOFORSK	Bioforsk
05	NFLI	Norsk institutt for skog og landskap
06	SINTEF-MC	Stiftelsen SINTEF
07	VRD	Vattenfall Research and Development AB
08	AKERSHUS	Akershus Energi AS
09	SKOGEIER	Norges Skogeierforbund
10	AGDER	Agder Energi AS
11	NTE	NTE Holding AS
12	HAFSLUND	Hafslund ASA
13	STATKRAFT	Statkraft Varme AS
14	NSKOG	Norske Skogindustrier ASA
16	PROTEIN	Norsk Protein AS
17	AVFALLN	Avfall Norge
18	BONDELAG	Norges Bondelag
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	Granit Kleber AS

G. References

R&D Agreement between RCN and the host institution UMB
Consortium Agreement

Annual Work Plan 2011
Annual Work Plan 2012
Annual Report 2011

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

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