Enabling sustainable and cost-efficient bioenergy

Annual Report 2013

CenBio - Bioenergy Innovation Centre

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

CenBio:
Bioenergy Innovation Centre

Annual Report 2013

Enabling sustainable and cost-efficient bioenergy industry in Norway

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

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

EDITORIAL

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(Photo: Gry Karin Stimo)

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(Photo: Elin Judit Straumsvåg)

2013 - The year of Midterm evaluation

FME CenBio was established in 2009 on a five-year contract with the Research Council of Norway (RCN). A successful midterm evaluation would extend the contract for another three years. In 2013, CenBio was evaluated by a panel of four international experts; two scientific experts on evaluating the research activities, and two experts on similar programs highlighting university and industry research collaboration.

The report from the evaluation panel had two main purposes: to form a basis for the RCN to decide upon prolongation of the Centre for the coming three years, and to identify the potential for improvements.

By the end of 2012, we produced the documents necessary for the evaluation panel. We described the scientific progress, education, innovations and feedback from all partners. On 20 March 2013, the evaluation panel met in Ås with the coordinators, manager, sub-project leaders, PhD students, Post Docs, representatives of the host institution and research and user partners of CenBio, in order to discuss the results and cooperation.

Main recommendations from the panel:

- CenBio is active at two distant sites, but the management has developed an efficient organization enabling smooth communication between the research partners, resulting in productive scientific research. However, there seems to be a need for more intense cooperation between different sub-projects to enhance the feeling of working towards a common goal.
- The challenge of CenBio is to implement an industry-driven approach for optimal application of bioenergy in Norway, where practical questions are ideally addressed with fundamental research, followed by applied research. As of yet, however, it appears that the prioritization of research topics is often insufficiently endorsed by industry, e.g., due to differences in time perspectives between researchers and industry.

The final three years

The expert panel identified a number of elements which could be improved. Thus, the Centre Executive Board proposed a list of improvements, most of which have now been actively implemented, including:

- Our common goal - *to enable sustainable and cost-effective bioenergy* – has been strongly re-affirmed by all partners
- We will run a foresight process to identify challenges, opportunities and priorities, with a long-term perspective
- Two CenBio annual conferences will stimulate the internal Centre coherence
- We will concentrate on industry needs, both short- and long-term
- We will establish a new advisory board
- We will strengthen the industry leadership of the Centre

The changes and the R&D-plan for the final three years were accepted by the Research Council by letter on 19 November 2013, successfully prolonging CenBio for the period 2014-2017.

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VISION AND GOAL

The vision of CenBio is to **enable sustainable and cost-efficient bioenergy industry in Norway**.

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

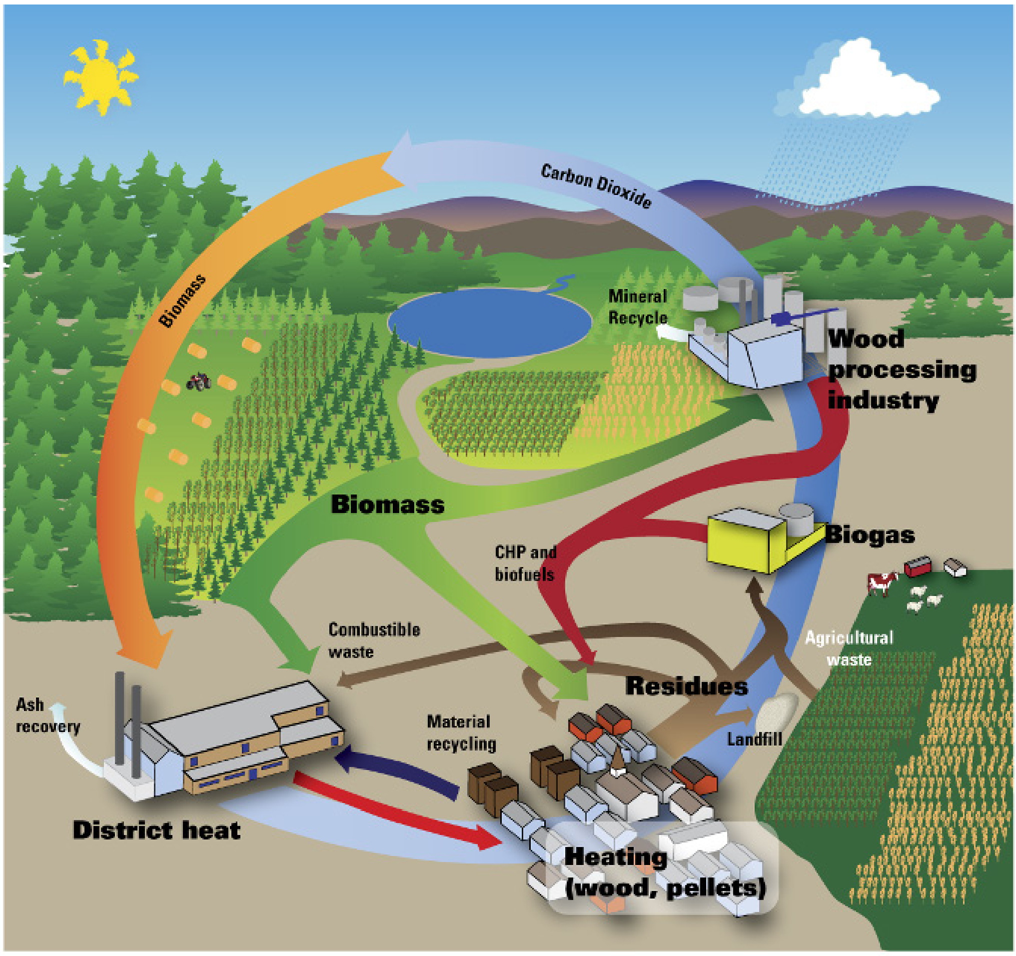

Figure 1: CenBio scope.

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.

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 NMBU. A new version of the description was submitted in November 2012, as requested by RCN. More detailed plan for the shorter term research activities is required, and an Annual Work Plan is to be submitted for RCN approval at the latest by 31 December each year. The Annual Work Plans will have to be based on the initial and less decisive description, but the course of the research may have to be changed due to external conditions.

Annual Work Plan 2014

The Annual Work Plan (AWP) 2014 was delivered to the RCN on 31 December 2013. The redaction of the document started at the SP level in September/October 2013, involving meetings with individual user partners to seek for the most relevant research topics. On 31 October 2013, a strategic meeting (CenBio Strategic Day) was organized to gather all CenBio researchers and user partners in order to discuss the various topics of interest for 2014 and beyond. This provided a strong basis for the redaction of the full document, which was first improved internally by the researchers and user partners, and then approved by the Executive Board (EB).

Joint laboratories

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

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

Biochemical conversion lab *Biogas lab* *Torrefaction unit*

Figure 2: Joint laboratories. (Photos: NMBU and SINTEF)

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ORGANIZATION AND COORDINATION

Einar Jordanger

Centre Manager

SINTEF Energi AS

(Photo: Gry Karin Stimo)

After a successful Midterm evaluation, CenBio has started to implement the list of improvements sent to the evaluation panel. The main axis of these improvements is to **induce stronger interactions** with both the user partners and the international research community and to **enhance the industrial utilization of the research work** performed within CenBio.

One of the first actions taken by the *Centre Management Team* (CMT) was to establish **a second annual event** involving all the actors from the Centre, which would take place around October each year. The main challenge for the Centre at that period of the year is to develop the *Annual Work Plan* (AWP) of the next year's research activities. The latter shall reflect the needs of the user partners and exploit the high potential for cooperation within the Centre. For this reason, the event was named ***CenBio Strategic Day*** and shall systematically be oriented toward the following year and beyond.

The original annual event of CenBio, namely the ***CenBio Days***, shall be as well **more open** to any bioenergy actor not directly involved in the Centre. In addition, its **duration shall as well be longer** to allow more interactions between researchers and user partners. Consequently, the *CenBio Days* are extended to three days instead of two, and are **made fully public**.

Naturally, the coordination of these two events requires specific resources and the involvement of several representative partners. Thus, the ***Organizing Team*** was created. Led by one member of the CMT, it includes one SP leader from Trondheim and one from Ås, one representative from the CenBio *Executive Board* and one representative from the user partners. This configuration enables integrating many inputs from the relevant actors of the Centre annual events. The *Organizing Team* shall meet regularly and discuss the critical aspects of the events, such as time, place, topics, speakers, etc. The work of the *Organizing Team* was greatly appreciated after the *CenBio Strategic Day* in October 2013 and the on-going preparation of the *CenBio Days* has taken into account any feedback received since then.

Regarding other relevant actions:

- **SP6**, the new sub-project focusing on value chain assessment, **was successfully established** across all CenBio partners.
- CenBio will coordinate a national **bioenergy foresight process** with a long-term perspective, planned for the first half of 2014.

The Centre has shown its ability to react positively and effectively to the Midterm evaluation to enhance the dynamic toward interactions with industry and the role of CenBio in the future of bioenergy in Norway.

Partners

Initially, 26 partners took part in CenBio. Norges miljø- og biovitenskapelige universitet (NMBU) is host institution and SINTEF Energi AS is coordinating institution. The governance structure is further detailed in Figure 3. Three partners left the Centre in 2011 (Xynergo AS, Afval Energie Bedrijft and BioNordic AS) and three in 2013 (Agder Energi AS, Norske Skogindustrier ASA and Norges Bondelag).

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

Research partners

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

User partners

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

- Akershus Energi AS
- Norges Skogeierforbund
- Nord-Trøndelag Elektrisitetsverk (NTE) Holding AS
- Hafslund ASA
- Statkraft Varme AS
- Norsk Protein AS
- Oslo Kommune Energigjenvinningsetaten (EGE)
- Vattenfall AB, Heat Nordic (Sweden)
- Energos AS
- Cambi AS
- Jøtul AS
- Granit Kleber AS

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Governance Structure

The governance structure of CenBio (2013), as defined in the Consortium Agreement is shown in Figure 3.

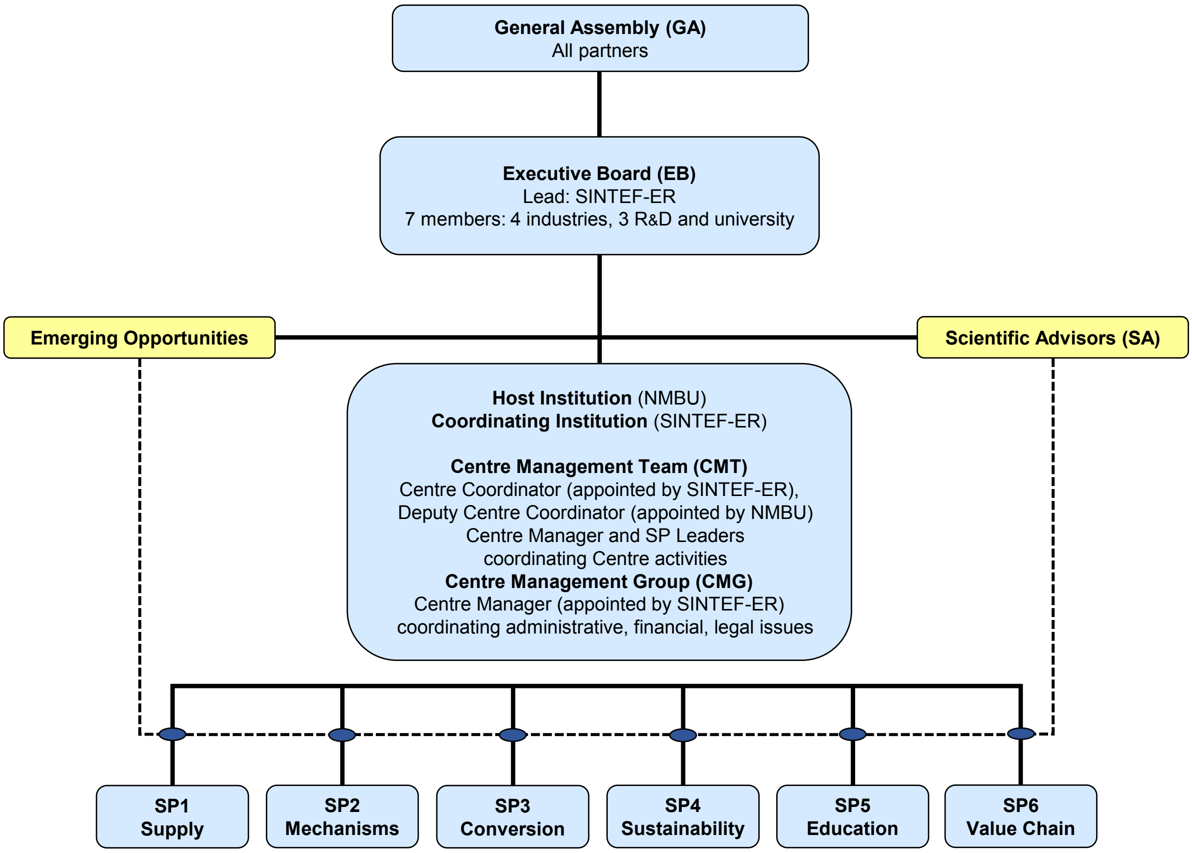

Figure 3: CenBio Governance Structure. SP stands for Sub-Project.

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 User partners. The Coordinating organization (i.e. SINTEF-ER) appoints the chairperson.

Table 1: Executive Board members 2013.

Position	*Name*	*Affiliation*
Chairperson	**Petter Støa**	02 SINTEF-ER
EB Member (Research partner)	**Olav Bolland**	03 NTNU
EB member (Research partner)	**Arne Bardalen**	05 NFLI
EB member (User partner)	**Erik A. Dahl**	09 SKOGEIER
EB member (User partner)	**Morten Fossum**	13 STATKRAFT
EB member (User partner)	**Hans Olav Midtbust**	22 ENERGOS
EB member (User partner)	**Pål Jahre Nilsen**	23 CAMBI

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	**Berta Matas Güell**	02 SINTEF-ER
Deputy Centre Coordinator	**Odd Jarle Skjelhaugen**	01 NMBU
Centre Manager	**Einar Jordanger** **Alexis Sevault**	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 NMBU
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 4.

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

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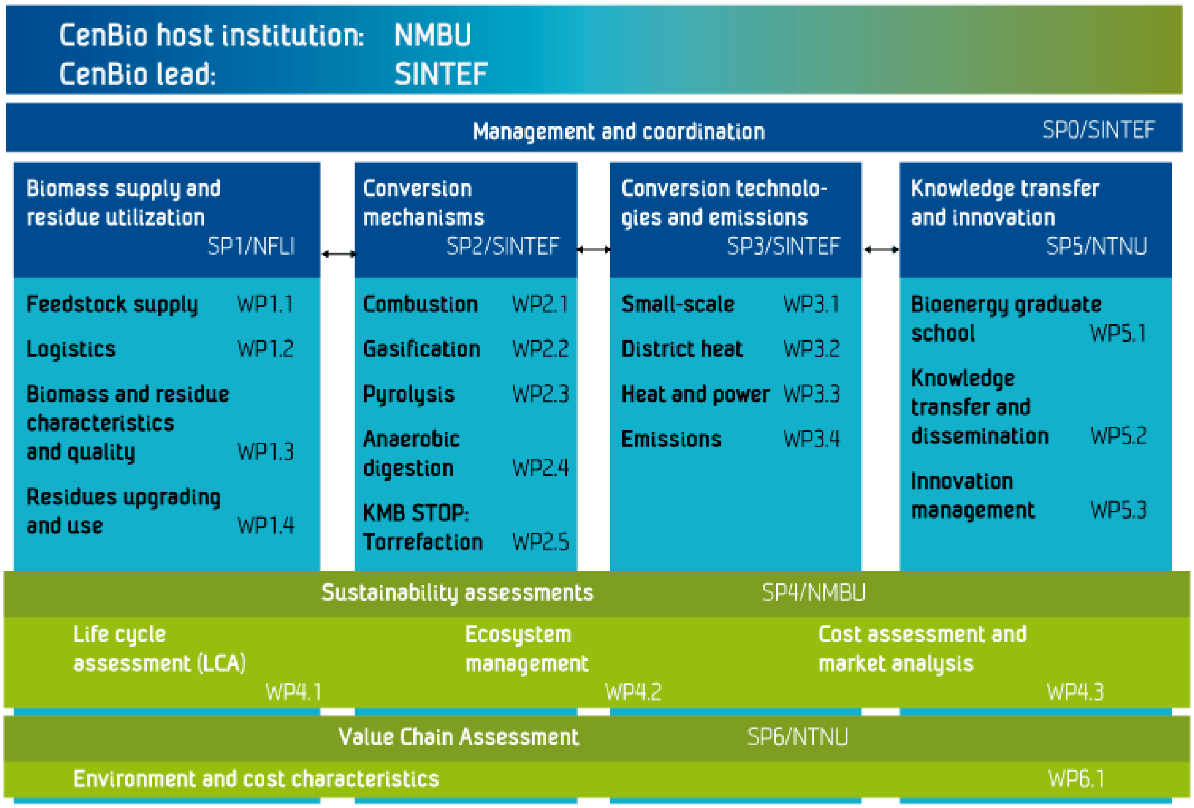

Figure 4: Work Breakdown Structure.

Cooperation between partners

The research activities in CenBio are mainly performed at universities and research institutes at Ås and in Trondheim. One R&D partner, Vattenfall R&D based in Sweden, works in close cooperation with SINTEF Energi AS. 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 user partners also contribute with in-kind research, and in some cases researchers from the universities or research institutes perform research at their installations.

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

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 2013, the CenBio Days took place in Trondheim on 10-11 April. Presentations from selected researchers and invited representatives from user partners were given in plenary sessions. Special topics, such as value chain assessment and innovations 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.

The CenBio Strategic Day was organized on 31 October 2013 in Trondheim to gather all the CenBio members (see Figure 5). This event happened for the first time in 2013 and enabled to discuss various topics of high importance for the Centre:

- Status after the midterm evaluation
- Preparing the final 3 years and beyond
- Value chain assessment (SP6): progress and ideas for 2014
- Inputs for the Annual Work Plan 2014.

Figure 5: CenBio Strategic Day 2013. (Photos: Alexis Sevault)

Management and Coordination

General

The overall coordination activities are organized within a separate work package, WP0.1 - Management and Coordination. During 2013, 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 organized the CenBio Days and the CenBio Strategic Day.

Project management system – the CenBio eRoom

A project management system for CenBio was established in 2009, where all relevant documents are uploaded. Personnel from all partners have access to the CenBio eRoom. By 31 December 2013, 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 2013, and the Core Management Team met twelve times. The Executive Board had five meetings, in May, June, September, October and December, and the General Assembly met on 10 April in Trondheim. Most CMT meetings are arranged as teleconferences using eRoom for sharing documents and information.

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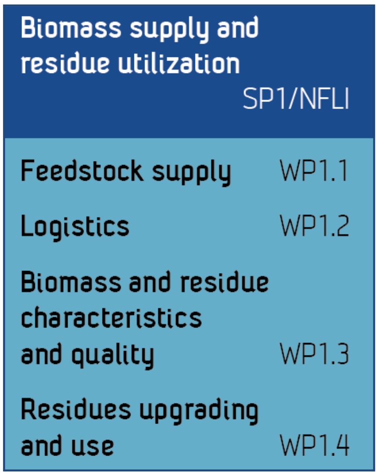
Deliverables list and Publication database

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 25.

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 40.

RESEARCH ACTIVITIES

SP1 BIOMASS SUPPLY AND RESIDUE UTILIZATION



Simen Gjølsjø

Leader of Biomass Supply and Residue Utilization

Norwegian Forest and Landscape Institute
(Photo: Lars Sandved Dalen)

Figure 6: WBS of SP1.

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 characterristics, 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 main activities of WP1.1 may be divided into three main parts:

- Developing new methods and models that can be used in inventories for assessing forest biomass and applying them to search potentially-available biomass resources for energy production at different institutional and geographical levels.
- Developing bio-economic optimization methods and models handling the linkage between biological production, silvicultural management, economic behavior, sustainability criteria and biomass supply and applying them in decision-support systems analyzing present and future potentially-available biomass resources energy production.
- Providing input on feedstock availability to value chains analysis and forest carbon dynamics following feedstock extraction for life cycle analyses.

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Methods and models for biomass assessment

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 at national and regional levels from residue harvesting. 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. There are two ways to bridge the gap: the general timber harvesting level can be increased, or the use of round wood for energy purposes can be increased at the expense of pulpwood. Given the present market conditions and the general policy framework for bioenergy production in Norway, it is not very likely that the gap can be bridged in a short term perspective (Bergseng et al.[1,2]).

In Norway, forest biomass is estimated using models developed in other parts of Scandinavia. This leads to a potential estimation bias as the models are applied outside the range for which they were developed. To remedy this, we have developed new birch biomass equations that are now undergoing scientific review (Smith et al., *in review*). We have then worked on improving methods for biomass estimation through the use of terrestrial laser scanners (TLS), as illustrated in Figure 7. We have in collaboration with Finish researchers carried out the first study of biomass estimation with TLS scanning on a large sample of root systems from mature Norway spruce.

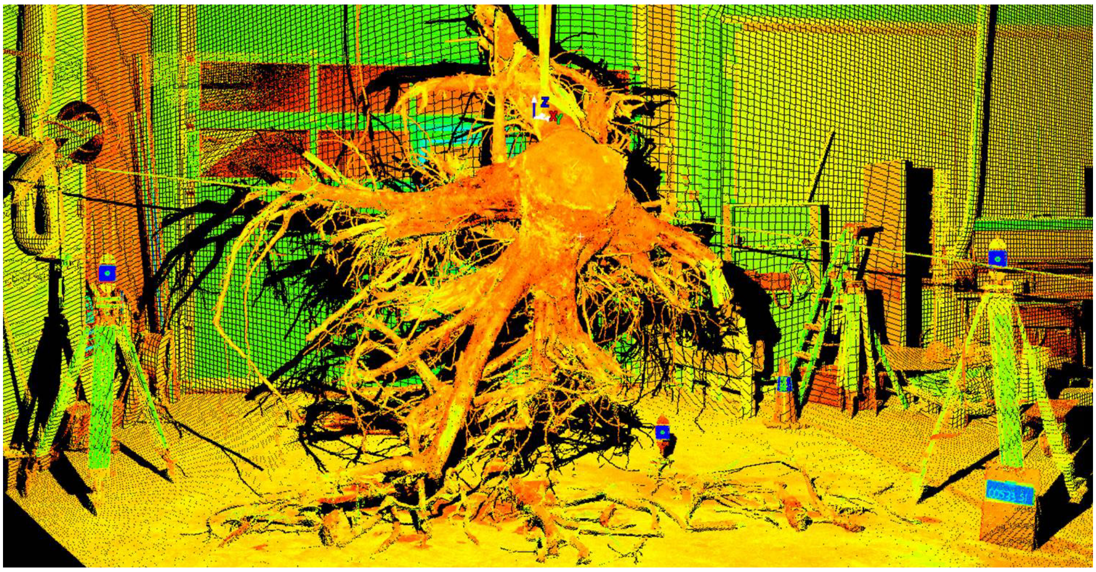

Figure 7: Example of terrestrial LiDAR scan of a tree stump. (Photo: Aaron Smith)

Bio-economic optimization

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 to preserve wildlife habitats or enhance scenic beauty. However, until now no decision support systems in Norway have incorporated

[1] Bergseng, E., Eid, T. & Løken, Ø. & Astrup, R., *Harvest residue potential in Norway – a bio-economic model appraisal.* Scandinavian Journal of Forest Research 28:470-480 (2013)

[2] Bergseng, E., Eid, T., Rørstad, P.K. & Trømborg, E. *Hva koster 16 TWh bioenergi fra skog? [What is the cost of getting 16 TWh from biomass in forest?]* Norsk Skogbruk 2/13: 36-37 (2013)

yet any functionality dealing with adjacency constraints. New methods applying simulated annealing (SA) have therefore been developed (Borges et al.[3,4]). Further work on methods development and case studies quantifying consequences of the adjacency constraints on timber- and biomass harvesting and the profitability are underway.

Value chains and life cycle analyses

Researchers from WP1.1 have participated with input in SP6 and will provide the regional inputs to the value chain assessments related to harvest, carbon dynamics, and albedo dynamics.

WP1.2 – Logistics

Progress and achievements in 2013

The most relevant progress has been made on the overall understanding of the various supply chain (from stump to conversion plant) alternatives. Knowledge of the various processes, their internal characteristics and response to changes in the external work environment is systematized in a simulation environment.

Achievements from this work include:

- **Journal paper**: Ger Devlin, Bruce Talbot, 2013. *Deriving cooperative biomass resource transport supply strategies in meeting co-firing energy regulations: A case for peat and wood fibre in Ireland*. Applied Energy 113 p. 1700-1709.

- **Journal paper**: Belbo H., Talbot B. 2014. *Performance of small scale straw-to-heat supply chains in Norway*. Wiley Interdisciplinary Reviews: Energy and Environment. DOI: 10.1002/wene.107.

- **Technical note**: Pierre Ackerman, Helmer Belbo, Lars Eliasson, Anjo de Jong, Andis Lazdins & John Lyons 2014. *The COST model for Calculations of Forest Operations Costs*. International Journal of Forest Engineering. Accepted for publication, not yet published.

- **Machine cost calculation tool** (spreadsheet template). *Output from Cost Action FP0902*, available for download at www.forestenergy.org.

- **Technical report**: Nordhagen, Kjøstelsen, Gjølsjø & Belbo 2013, *Logging residues from cable logging* (in print)

- **Decision support tool** (based on spreadsheet calculations) for supply chain configuration (90% completed).

[3] Borges, P., Bergseng, E. & Eid, T., *Adjacency constraints in forestry – applying simulated annealing using different methods for the neighborhood exploration*. European Journal of Operational Research 233: 700-710 (2014)

[4] Borges, P., Bergseng, E. & Eid, T., *Adjacency constraints in forestry – a simulated annealing approach comparing different candidate solution generators*. Accepted Mathematical and Computational Forestry and Natural-Resource Sciences (MCFNS) (2014)

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- **International collaboration** has improved especially towards Skogforsk in Uppsala (Sweden) and School of Biosystems Engineering in Dublin (Ireland).

- Another relevant activity is the improved knowledge on logging residues from yarding operations, i.e. expectations for volume output, and optional treatments and technologies to turn this waste into a useable biomass resource.

Examples of collaborations with other SP/WP and user partners

- Improved collaboration with WP1.1 (Feedstock supply) will be a necessity for further work on supply optimization and decision support tools. This collaboration has been initiated, but not yet materialized in common outputs.

- SP6 will definitively require and enhance stronger collaboration with other WPs.

- A project proposal focusing on new biomass transport modes / methods was sent to *Utviklingsfondet for skogbruket*[5], with Allskog[6] and Statskog[7] as user partners, though it was regrettably not prioritized by the jury. However, the application process lowered the door sill for future collaboration with these partners.

International collaboration

- We have, in the period 2009-2013, been part of COST Action FP0902 Forest Energy[8], as part of the management committee and various working groups. Main outputs from this work, beside general networking and information exchange, are a machine costing calculation tool with an accompanying technical note, a booklet of guidelines for field studies of biomass production systems.

- We are currently part of IEA Bioenergy Task 43[9], Biomass Feedstocks for Energy Markets, where Simen Gjølsjø and Bruce Talbot are our national team leaders.

- We are currently part of the team aiming to establish a new EU COST Action named Techno-Diversity in Forestry.

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 feedstocks, in order to produce an optimized fuel with reduced emissions, have been also investigated. These 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.

[5] https://www.slf.dep.no/no/eiendom-og-skog/skogbruk/utviklingsfondet-for-skogbruk

[6] http://www.allskog.no/

[7] http://www.statskog.no/Sider/forsiden.aspx

[8] http://www.forestenergy.org/

[9] http://www.ieabioenergytask43.org/

Characterization of spruce as fuel

Background

The release and transformation of alkali metals and heavy metals are strongly relevant for different operational problems in bioenergy production system. It is important to obtain reliable quantitative data for release of alkali metals during thermal conversion of biomass fuels. Intensive experiments and analyses have been performed through joint work between researchers in Åbo Academy in Finland and SINTEF Energy Research and NTNU in Norway. Thermal conversion of biomass pellets was performed in a novel Single Particle Reactor (SPR). In total, four fuels were converted at two gas atmospheres, three peak temperatures and four different holding times. The gas atmospheres were: 1. (3% O_2 + 97% N_2) and 2. (100% N_2). The temperatures were 800 °C, 900 °C and 1050 °C, respectively. The four holding times were: devolatilization, 50% char burnout, char burnout and char burnout with extra 5 minutes time. The inorganic species in the fuel, the char residues and ash samples after experiments were analyzed by both ICP-AES and ICP-MS analysis. Selected char and ash residues after fuel conversion were collected and further analyzed by SEM-EDX and XRD.

Results

The fuel chemical composition analysis results are presented in Table 4. The concentrations of most of ash forming elements in the bark are much higher than those of the wood. For the K, P, S and Mg, they are soluble in different types of sap solutions and might translocate between different parts of the tree. These elements are likely to accumulate in the young and biological active tissues with rather higher water contents. The bark contains significant amounts, such as active tissues and large fraction of ash forming elements as well.

Table 4: Ash content and chemical composition of the spruce bark and spruce wood.

	Ash content (weight %)	*Ca*	*Si*	*K*	*Na*	*Mg*	*Al*	*P*	*S*	*Mn*	*Fe*	*Cu*	*Zn*	*Cl*	*Si/K*	*Si/(Ca+Mg)*
Spruce bark	5.0	12900	3180	1840	98	813	733	335	301	675	528	4	82	98	2.4	0.32
Spruce wood	0.48	1160	83	574	7	243	15	60	38	75	253	1	28	11	0.20	0.08

Figure 8 shows that fraction of K released from spruce bark and wood increased as function of conversion temperature and residence time at a particular temperature. During the spruce bark and wood combustion at low temperature 800 °C, the K released is mainly related to volatilization of organically bonded K in the char matrix. At temperatures of 900 and 1050 °C, the release of K is mostly due to formation and decomposition of potassium salts such as K_2CO_3. Figure 9 shows sintering of the bark ash into large aggregates at elevated temperatures.

The K release profiles at 1050 ˚C were significantly different for the spruce bark and the spruce wood. Compared to spruce bark, the relative concentration of key inorganic elements like Si, to K (Si/K) and Si to Ca and Mg (Si/Ca+Mg) are quite low, as presented in Table 1. Fuel chemical composition of the spruce wood is favorable for potassium release as observed in the study.

Results obtained from the work will be further processed to submit a journal and/or a conference publication.

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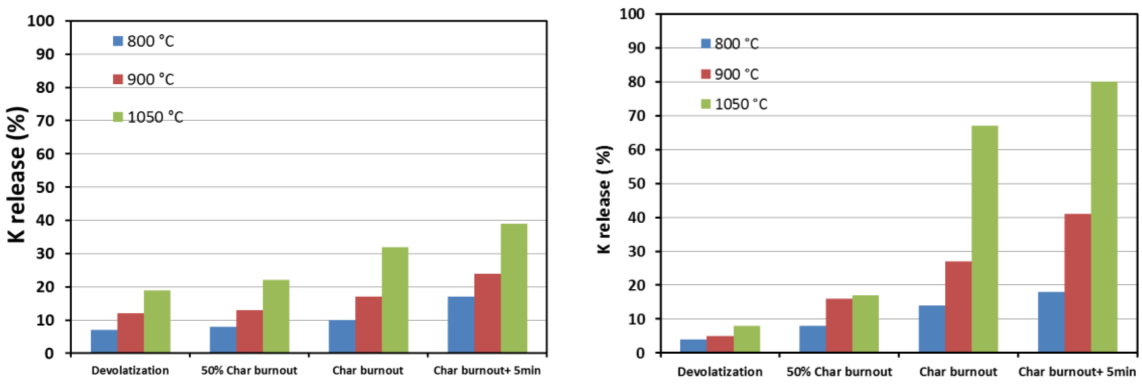
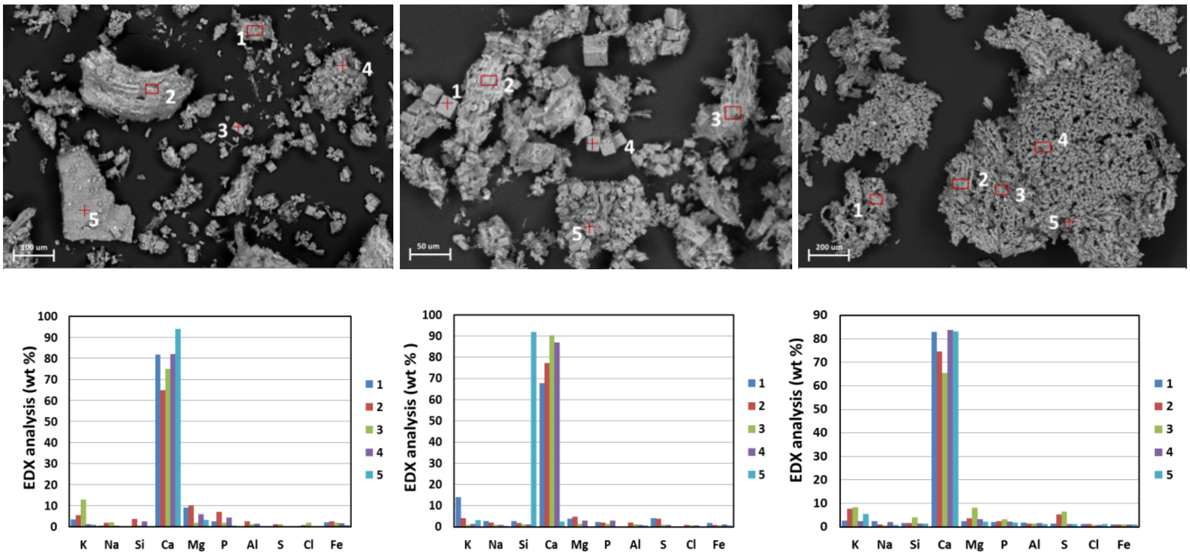


Figure 8: Release of K as function of conversion temperature and time.



(1) 800 °C *(2) 900 °C* *(3) 1050 °C*

Figure 9: SEM-EDX analysis of residues collected after spruce bark combustion experiments.

Wood chip characterization

Background

The bioenergy sector is a relatively new sector in forestry and has focused on developing a cost-effective value chain. NLFI has implemented a project that has delivered quality descriptions for wood chips. NLFI has analyzed and measured chip size, density, moisture, chemical composition, ash and calorific value of wood chips from forest[10]. The methods used are based on bioenergy standards. The chip material has been analyzed at the *Forest biomass* laboratory at NLFI (cf. Figure 10).

Wood chip quality

European Standards define the fuel quality classes and specifications for solid biofuels. The EN standards are tools for international trade of solid biofuels. NFLI has analyzed

[10] http://www.skogoglandskap.no/nyheter/2013/fliskvalitet_i_det_norske_flismarkedet/newsitem

approximately 125 chip samples for particle size distribution, moisture content, bulk density, ash content, calorific value and energy density (see results in Table 5).

Figure 10: The Forest biomass laboratory at NLFI. (Photo: NFLI)

Table 5: Properties of wood chips.

	Logging residues	Whole trees	Stem wood	Bark	Wedge wood
Moisture *(w-% as received)*	49.8	39.9	39.8	69.9	39.3
Bulk density (BD) as received *(kg/lm³)*	356	278	251	433	296
Bulk density, dry *(kg/lm³)*	174	166	156	130	169
Ash *(w-% of dry basis)*	2.26	0.94	0.37	2.92	0.37
Net calorific value in dry and ash-free basis *(kWh/kg)*	5.47	5.25	5.25	5.50	5.25
Net calorific value as received *(kWh/kg)*	2.40	2.92	3.02	1.13	2.79
Energy density as received *(kWh/lm³)*	826	791	753	490	801

Chip size

Average and cumulative size distribution of logging residue, whole trees and stem wood chips are shown in Figure 11. For logging residues chips, 50 % of the particles were less than 8.9 mm. For whole trees and stem wood chips, 50 % of the particles were less than 12.5 mm. Chips from stem wood contained on average 5.5 % particles less than 3.15 mm, while chips from logging residues contained approximately 24 %.

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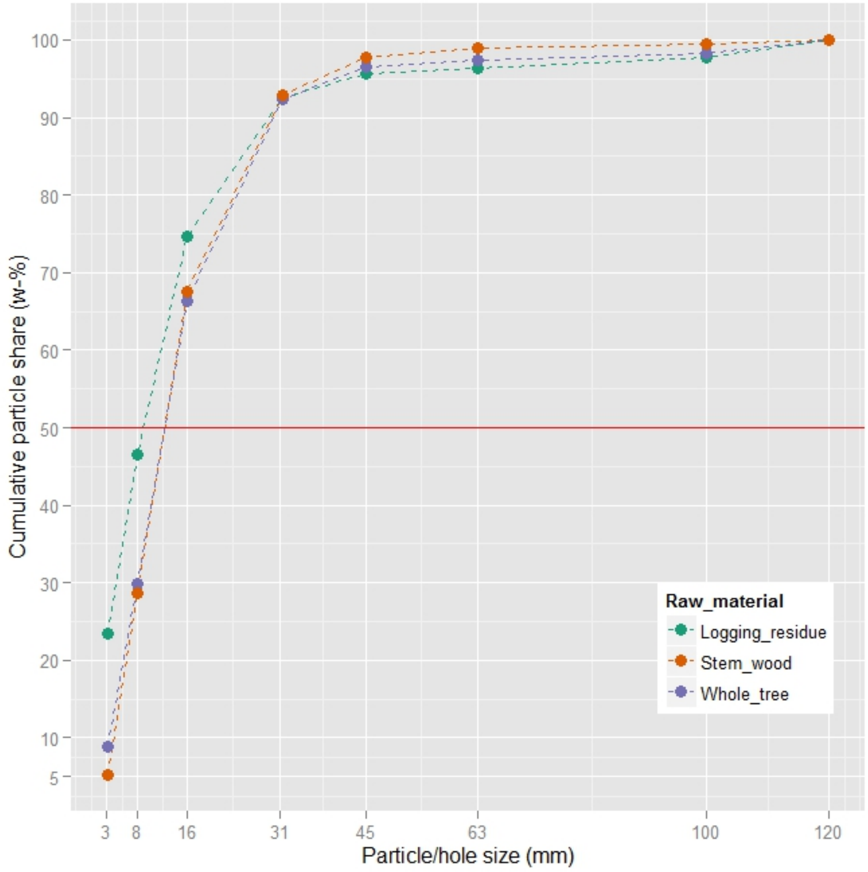

Figure 11: Average and cumulative size distribution of logging residue, whole trees and stem wood chips.

WP1.4 – Residue upgrading and use

Background

The main activities in WP 1.4 are related to utilization of different types of ash (wood ash and MSWI ash), and different types of anaerobic digestates. These residues are end products after combustion and anaerobic digestion, respectively.

Research and results

The research has been especially focused on the potential for recycling of phosphorus from ash and solid anaerobic digestates, as previous plant growth experiments carried out as part of this WP have shown unexpected high plant-availability of phosphorus in wood ash.

In 2013, a laboratory study on different extraction methods for phosphorus was combined with a pot experiment for testing the plant availability of P from different types of wood ash and anaerobic digestates. These results confirmed our results from previous studies that a much higher proportion of P in wood ash is plant-available than with the commonly used chemical extraction methods indicated. This study represents a part of the Ph.D. work of Eva Brod, and a journal publication presenting these experiments will be prepared in 2014. In 2013, one scientific journal publication on ash utilization was submitted to Acta Agriculturae

Scandinavica, Section B Plant and Soil Science, which, hopefully, will be accepted for publication within 2014.

In addition, published material from this WP on properties of Norwegian wood ash and potential utilization have been included in a report from the Norwegian Geotechnical Institute to Miljødirektoratet as a part of the work with new regulations on utilization of organic waste resources and residues of organic origin.

Figure 12: (A): Phosphorus-rich waste materials used as fertilizer in a pot experiment. (B): The setup of pot experiments. (C): Harvesting the pot experiments. (D): Harvested pots. (Photos: Eva Brod)

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SP2 CONVERSION MECHANISMS

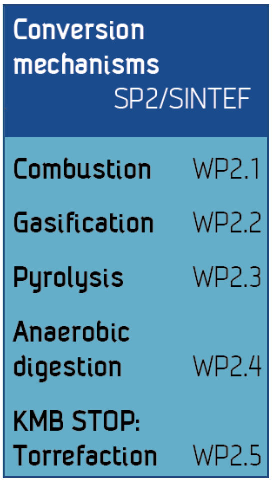


Figure 13: WBS of SP2.

Michaël Becidan

Leader of Conversion Mechanisms

SINTEF Energy Research

(Photo: Gry Karin Stimo)

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

The work on combustion addresses operational challenges encountered in Biomass-to-Energy (BtE) plants, especially ash-related ones, namely corrosion, slagging and fouling. The extensive testing of novel additives to fight these challenges and evaluating their efficiencies with fuels such as barley husk and straw, is a significant achievement of CenBio.

Pyrolysis activities focus on enabling energy efficient biocarbon (bio charcoal) production. This is a novel fuel with 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 - replacing the fossil fuels commonly used today - to ensure 100% renewability in BtE plants. Increasing the pressure in the process has proven interesting – increasing both the charcoal and fixed carbon yields. 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 at Manoa (USA). This activity was so successful and promising, that a spin-off project, KPN BioCarb+, was awarded by RCN in June 2013 and started January 2014 with a total budget of 20 MNOK over 4 years.

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.

The fuel pre-treatment technology torrefaction is also an integral part of CenBio through the RCN KMB STOP project that finished in December 2013, except for the PhD candidate who will complete his work in 2014. This is a mild pyrolysis process (200-300 °C for dry torrefaction), leading to enhanced grindability, better homogeneity and increased energy density and improved logistics properties when densified to e.g. pellets.

WP2.1 Combustion

Additives to abate ash-related challenges during thermal treatment

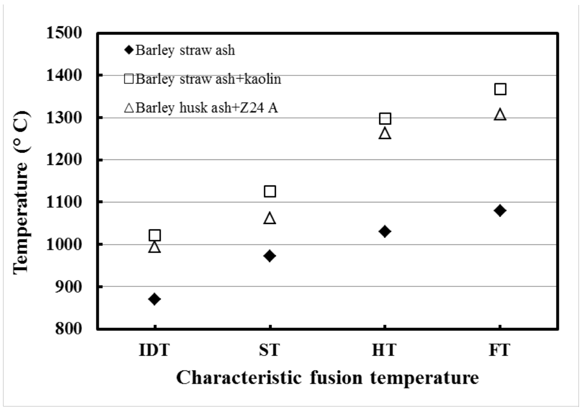
Testing zeolite and kaolin additives

This activity centered on the testing of zeolite and kaolin to prevent ash sintering and fouling during biomass combustion. The main tasks and results can be summarized as such:

The formation and release of gaseous corrosive potassium chloride (KCl) during biomass combustion cause ash sintering and deposition during combustion of biomass. Zeolite 24A and kaolin (both aluminium silicates) were tested in the lab (via thermogravimetric study) in terms of their capacity to capture KCl in the solid phase. It was found that, instead of evaporating into the gas phase, a significant fraction of KCl was retained in zeolite 24A and kaolin at 1000 °C. The KCl was captured by zeolite 24A and kaolin through a combination of physical adsorption and chemical reactions. It indicates that the use of the two additives during biomass combustion can reduce alkali metals release and abate fouling deposits.

The two additives were also tested to reduce the sintering propensity of barley straw ash. The addition of kaolin and zeolite 24A significantly increased the melting temperature of the barley straw ash as shown in Figure 14. At the same time, severe sintering of the barley straw ash (Figure 15-a) was reduced. The resulting ash contains loose structure and a partially melted fraction, as shown in Figure 15-b and Figure 15-c. Together with SEM-EDX analysis, identification of high melting temperature potassium aluminium silicates by XRD partly explains the improved sintering behaviours of the ash-additive mixtures.

One peer-reviewed paper[11] (cf. Figure 16) was produced based on the results from this study. The paper was presented at the 16th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction by SINTEF-ER research scientist Liang Wang. The paper was published in Chemical Engineering Transaction (ISSN 1974-9791). In addition, the paper was invited for a submission to a Special Issue of Applied Thermal Engineering (Elsevier) dedicated to the conference.



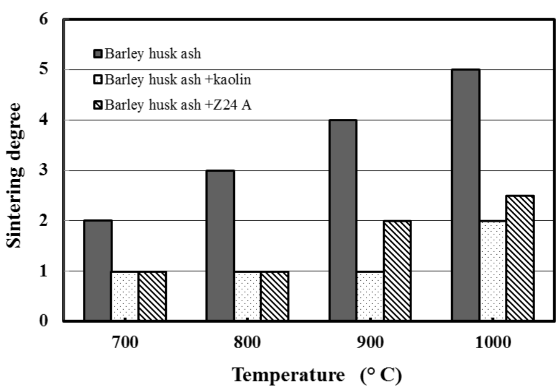


Figure 14: Melting and sintering behavior of the barley straw ash and the effects of additives

[11] Wang L., Becidan M., Skreiberg Ø., *Testing of Zeolite and Kaolin for Preventing Ash Sintering and Fouling during Biomass Combustion, Chemical Engineering Transactions, Vol. 35 (2013) DOI: 10.3303/CET1335193*

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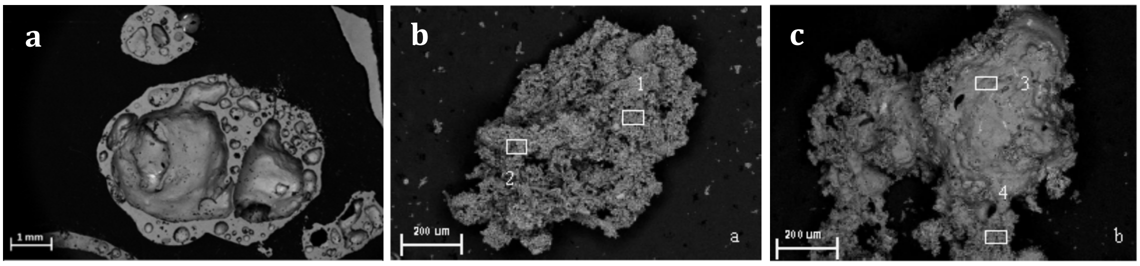
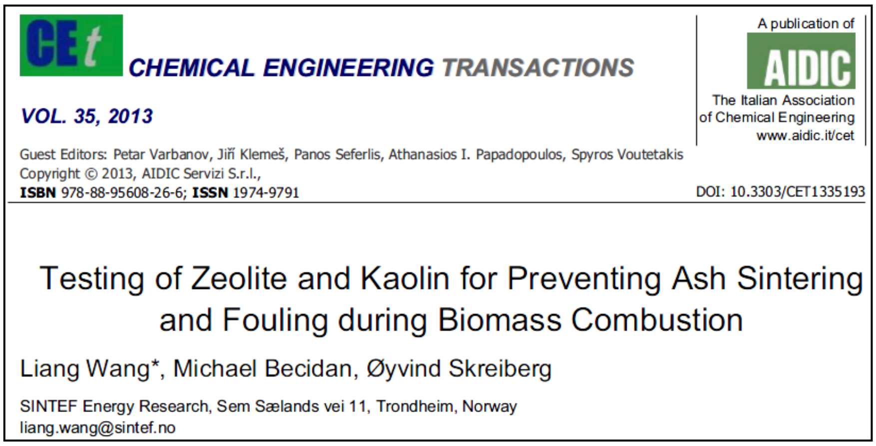


Figure 15: SEM image of mixture of barley straw ash (a) fused fraction, (b) with kaolin addition and (c) with zeolite addition after sintered at 1000°C.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Testing of Zeolite and Kaolin for Preventing Ash Sintering and Fouling during Biomass Combustion

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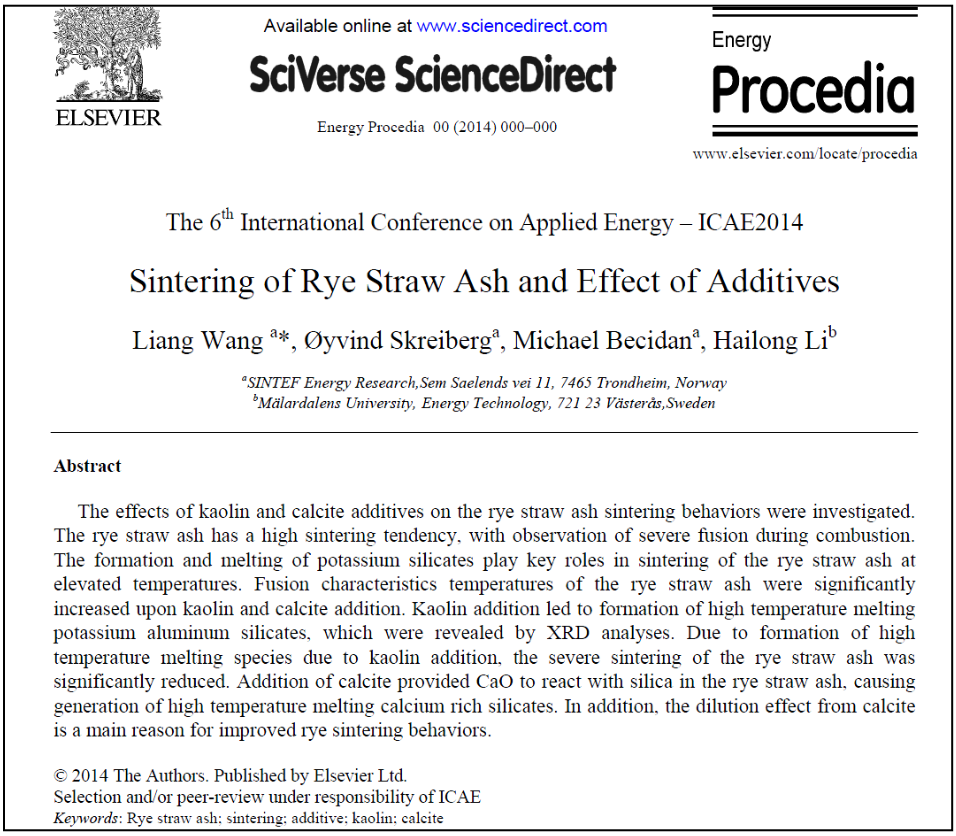
Figure 16: Paper published in Chemical Engineering Transaction.

Sintering of rye straw

In Nordic countries, rye straw is available in large amounts and can be burnt for heat and power production. However, ash sintering and slagging often occur during combustion of this biomass fraction and limit the utilization of this valuable residue. However, the knowledge about the sintering behaviors of ashes derived from rye straw is still fragmented; in consequence CenBio carried out work to improve this situation. This work yielded several interesting results:

- Sintering of rye straw ash and the effect of additives were investigated. It was found that the rye straw ash has a high sintering tendency, including severe fusion during combustion. The formation and melting of potassium silicates plays a key role in the sintering of rye straw ash at elevated temperatures.

- The characteristic fusion temperatures of the rye straw ash were significantly increased upon kaolin and calcite addition. Kaolin addition led to formation of high temperature melting potassium aluminum silicates, which were revealed by XRD analyses. Consequently, the severe sintering of the rye straw ash was significantly reduced. Addition of calcite provided CaO to react with silica in the rye straw ash, causing the formation of high melting temperature calcium-rich silicates less prone to sintering.



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The 6th International Conference on Applied Energy – ICAE2014

Sintering of Rye Straw Ash and Effect of Additives

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Abstract

The effects of kaolin and calcite additives on the rye straw ash sintering behaviors were investigated. The rye straw ash has a high sintering tendency, with observation of severe fusion during combustion. The formation and melting of potassium silicates play key roles in sintering of the rye straw ash at elevated temperatures. Fusion characteristics temperatures of the rye straw ash were significantly increased upon kaolin and calcite addition. Kaolin addition led to formation of high temperature melting potassium aluminum silicates, which were revealed by XRD analyses. Due to formation of high temperature melting species due to kaolin addition, the severe sintering of the rye straw ash was significantly reduced. Addition of calcite provided CaO to react with silica in the rye straw ash, causing generation of high temperature melting calcium rich silicates. In addition, the dilution effect from calcite is a main reason for improved rye sintering behaviors.

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Selection and/or peer-review under responsibility of ICAE
Keywords: Rye straw ash; sintering; additive; kaolin; calcite

Figure 17: Paper accepted by the 6th International Conference on Applied Energy-ICAE 2014.

Based on results obtained from the study, one paper[12] was submitted and accepted by the 6th International Conference on Applied Energy for publication (ICAE 2014, cf. Figure 17).

NOx reduction by primary measures

Detailed modeling of NOx formation is extremely complex and reduced (simplified) chemical kinetics mechanisms may not be able to model adequately the combustion process.

In this activity, previously developed reduced kinetics mechanisms[13] were applied to an ideal flow reactor and their ability to reproduce experimental data[14] tested. In addition, the full mechanism (from where reduced kinetics are derived) was tested against experimental data and its quality was compared to the performance of earlier full mechanisms[15]. This work was published in Energy and Fuels[16].

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[12] Wang L., Skreiberg Ø., Becidan M., Li H., *Sintering of rye straw ash and effects of additives*, Energy Procedia - 6th International Conference on Applied Energy-ICAE 2014 (paper accepted)

[13] 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)

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

[15] 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)

[16] Terese Løvås, Ehsan Houshfar, Mette Bugge, Øyvind Skreiberg. *Automatic generation of kinetic skeletal mechanisms for biomass combustion*. Energy & Fuels 27(11):6979-6991 (2013)

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In more details, simplified kinetics mechanisms for gas phase biomass combustion were presented, based on automated reduction of detailed and comprehensive kinetics mechanisms. The reduction method that has been employed is a combined reaction flow analysis and sensitivity analysis, well-known in combustion, resulting in a necessity index ranking all chemical species for automatic reduction. The objective is to obtain more compact chemical models, so-called skeletal mechanisms, for implementation into computational fluid dynamics (CFD) in order to reduce computational (CPU) time.

In the current work, the physical system used for the development and validation of the chemical models is that of a tubular reactor, or plug flow reactor, with operating conditions typically found in biomass reactors. The focus has been on gas phase reactions only, and the fuel composition is based on experimental values from biomass and coal gasification. Emphasis has been on the reliability of the simplified models and the correct prediction of important emission parameters such as NOx (and important intermediate species). The original chemical model, consisting of several sub models for important reaction paths known in biomass combustion, contained 81 species and 1401 reactions. This was successfully reduced down to 36 species, providing a compact and reliable chemical model for implementation into CFD. The model still contains the reaction paths of C2 species, allowing for more realistic fuel gas compositions. The model has been experimentally validated for a wide range of temperatures including low temperature chemistry and reducing conditions for NOx. The computational time saved using the simplified models was significant with over 80% reduction in CPU time.

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, as well as the correctness of the reduced kinetics, expressed as valid modeling condition ranges.

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).

The ultimate aim is to identify the combustion conditions for minimal NOx production. The most important parameters are the primary excess air ratio and total excess air ratio, while temperature is less important in the typical temperature range of a grate fired reactor.

A CenBio PhD study:
Numerical simulations of turbulent flames increase our understanding and control possibilities in biomass combustion

Dmitry Lysenko: *On Numerical Simulation of Turbulent Flows and Combustion*, PhD thesis, Department of Energy and Process Engineering, NTNU 2014. Supervisors: Ivar S. Ertesvåg (*Professor, NTNU*), Kjell Erik Rian (*Dr.ing., ComputIT, Trondheim*).

Improved efficiency of biomass energy conversion can be achieved by gasification and subsequent combustion in gas turbines. Efficient and clean utilization of biomass depends (among others) on combustion technologies. This requires a deeper understanding of the basic processes of turbulent reacting flows. The underlying challenges include the flame behavior, turbulence mixing properties, flame stability at high pressure, peak temperatures, pollutant formation, etc.

The emphasis of this PhD work is on advancing the modeling of interactions between turbulence and reactions by integrating current practice of chemical kinetics into new combustion models. The aim was to develop a turbulence-chemistry interaction model for turbulent combustion simulations for high Reynolds number flows of practical interest. Simulations were carried out using the unsteady Reynolds-averaged Navier-Stokes (URANS) and Large Eddy Simulation (LES) formulations. Compressible flow treatment was used for in order to model the coupling between fluid mechanics and thermodynamics. The interaction between turbulence and chemistry was modeled based on the Eddy Dissipation Concept (EDC) with a detailed chemistry treatment. The open-source code OpenFOAM was used for the numerical simulations.

First, non-reacting turbulent bluff-body flows were investigated with the goal of validation, verification and understanding of the capabilities of the numerical method using the conventional URANS approach. These results were analyzed in detail and agreed fairly well with experimental data. Then, the validation of the URANS approach (based on the standard k-ε model) was extended for reacting turbulent flows. The chemistry was described by the full GRI-3.0 mechanism. There was relatively good agreement between simulations and measurements. Furthermore, the numerical method was extended to a large-eddy simulation model. Again, non-reacting flows were simulated to evaluate the applicability of the implemented LES approach.

Finally, the method was used for the turbulent reactive flow predictions with LES and the Eddy-Dissipation Concept. The simulations were validated against experimental data, and reasonable agreement was achieved.

The thesis consists of six journal articles, four of which are accepted, and will be defended on 13 March 2014.

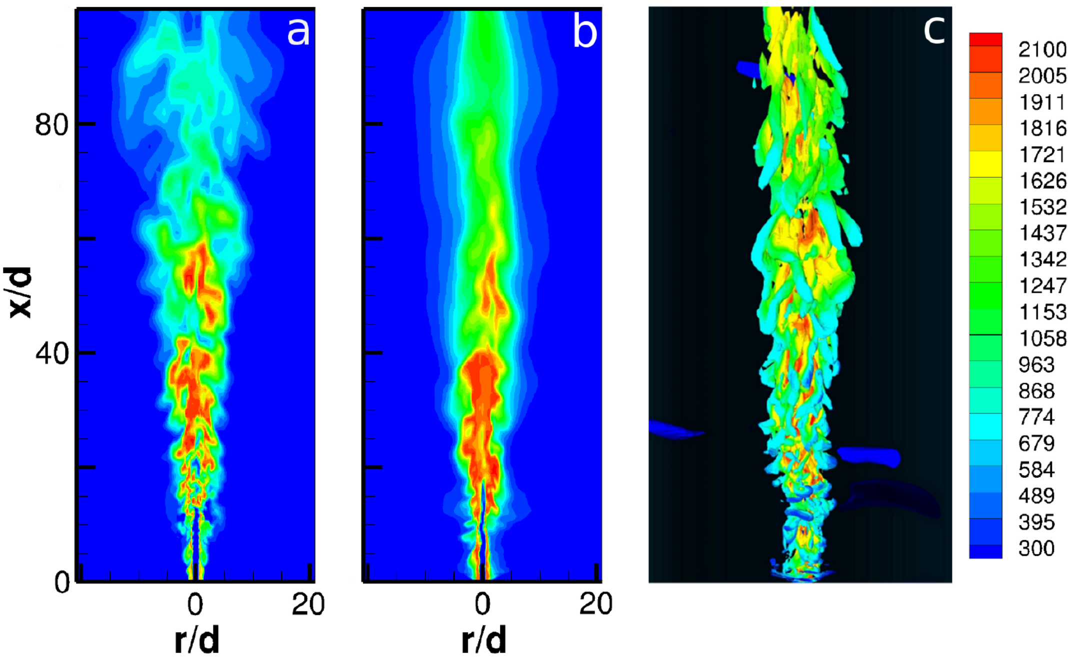

Figure 18: Instantaneous iso-surfaces of temperature (K) resulting from the simulations of turbulent flames (Sandia Flame D) obtained using various numerical models. Source: Lysenko et al.[17]

[17] Dmitry A. Lysenko, Ivar S. Ertesvåg, Kjell Erik Rian, *Numerical simulations of the Sandia Flame D using the Eddy Dissipation Concept; Paper under review.*

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The bioenergy laboratory in Trondheim is at a high international level thanks to CenBio investment funds

Over a three-year period, a number of investments in the joint bioenergy laboratory of SINTEF and NTNU have been made by scientific investment funds awarded to CenBio by the Research Council of Norway. The investments include:

- Climate room and climate cabinet for temperature and air humidity controlled fuel storage
- Various fine laboratory upgrades enhancing experimental and analysis capabilities
- A range of thermogravimetric analyzers for testing thermal decomposition characteristics and kinetics of biomass fuels
- Gas analyzers and connected equipment
- Autoclave and ICP-OES for sample preparation and elemental analysis
- Pressurized and temperature controlled bench scale reactors for pyrolysis and wet torrefaction studies.

The most recent addition is a high-pressure TGA (cf. Figure 19) that will be extensively used to study the thermal decomposition characteristics and kinetics of various biomass fuels at pressurized operating conditions, both in CenBio and in the newly started spin-off project KPN BioCarb+ (Enabling the biocarbon value chain for energy).

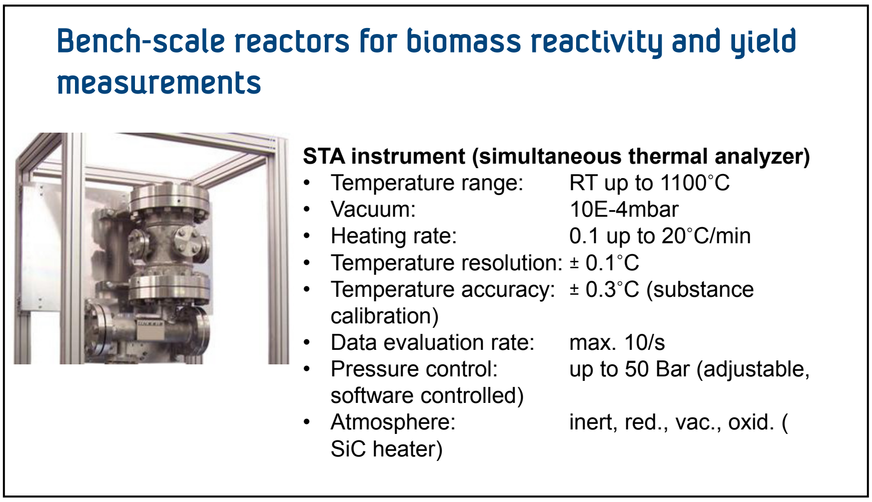

Figure 19: The high-pressure TGA financed by the Research Council of Norway.

These investments together with other investments made possible through SINTEF Energy Research strategic funds (and also through other projects) have greatly enhanced SINTEF's capabilities to produce high level research results within thermal conversion of biomass and waste.

International collaboration through participation in, e.g., the IEA Bioenergy Task 32 Biomass Combustion and Cofiring is essential

International orientation and collaboration is very important for a national bioenergy centre. Such collaboration, e.g., through IEA tasks, leads to network building and information access and exchange, ultimately leading to competence building in Norway, international project participation or leadership opportunities (e.g., in EU projects) and high level joint publications with renowned international institutions within the bioenergy area.

Participation in IEA Task 32 Biomass Combustion and Cofiring has through decades contributed to NTNU and SINTEF internationalization and the task has produced a large number of valuable reports and other publications. It has hosted numerous meetings and workshops on key areas and issues within biomass combustion, and later also fuel upgrading by torrefaction. *See www.ieabcc.nl for further info.*

WP2.2 Gasification

The main activity of this work package in 2013 focused on a conference article[18] entitled "A Simplified Approach for Municipal Solid Waste Gasification Modelling". It was published in the Proceedings of the Fourteenth International Waste Management and Landfill Symposium, by CISA Publisher (Italy). For the first time in CenBio, this article was a direct cooperation between the industry (Energos) and an R&D institution (SINTEF Energy Research).

WtE or EfW (Waste-to-Energy or Energy-from-Waste) has, in spite of its opponents, shown itself to be of growing importance in the context of energy resources' depletion and climate change. In such process, producing a high calorific value syngas while keeping the emissions below the limit is the key point. Therefore, the constant improvement of gasification process plays a major role in the WtE plants. On the other hand, emissions such as NO_x, N_2O, CO, C_xH_y, SO_x, PM, HCl, and unburnt carbon in the bottom ash are affected by the process optimisation variables.

In order to understand and improve the performances of gasification processes, modelling is central. For a given chemical reaction system, two approaches exist for prediction of the product species: global equilibrium analysis (GEA) and stoichiometric equilibrium modelling.

In this work, the two approaches were compared according to the following procedure:

1. GEA modelling of the syngas formation from the Energos process (Figure 20) under various temperatures using the FactSage software package, since currently, process control systems for WtE plants are based on the flue gas online measurement and some input parameters, e.g., air ratio (λ), temperature etc.;

2. Then, for the given syngas composition, temperature is calculated based on the assumption of having only the water-gas-shift (WGS) reaction and compared with the original calculation temperature.

[18] E. Housfar, M. Becidan, P. Lundstrøm and A. Grimshaw. *A Simplified Approach for Municipal Solid Waste Gasification Modelling*. Proceedings of the Fourteenth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy; 30 Sep.– 4 Oct. 2013 (CISA Publisher, Italy)

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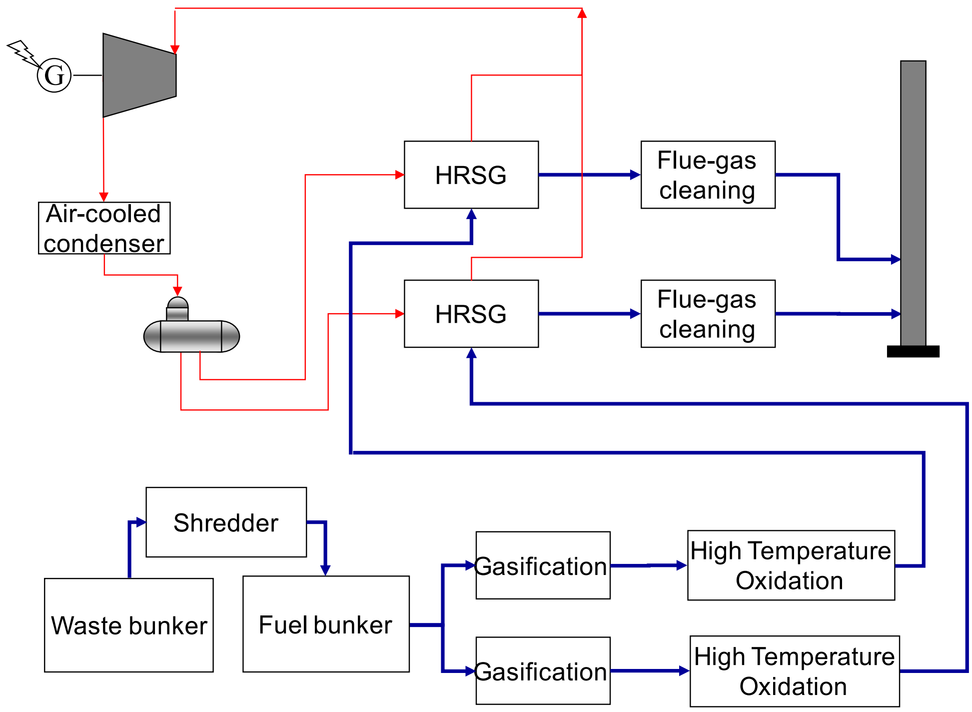

Figure 20: Process flow in a typical Energos EfW plant.

In addition, the influence of temperature on syngas formation is thoroughly discussed using the equilibrium model. The experimental validation is performed by sampling the syngas from two operating Energos' WtE plants in Isle of Wight (UK) and Sarpsborg (Norway). A simplified method is introduced in which the composition of syngas from a waste gasification process can be calculated from the WGS reaction. This implies that, if the mathematically complex approach of Gibbs free energy minimization is used, then the results will be, essentially, identical to the results obtained from applying the WGS reaction only, as long as the syngas temperature of interest is in the range 600 °C to 1500 °C. The only species available for WGS reaction are CO_2, CO, H_2O and H_2, where the measurements of these gases verify the equilibrium constant method. In a real furnace, there are of course other gas species present in the syngas flow, e.g., CH_4, O_2, and C_2s which cause an overestimation of concentrations if we use only WGS reaction. The formation of these species are related to hot spots, surface/heterogenous reactions, imperfect mixing condition, local oxygen availability, etc.

Equilibrium models are efficient tools for parametric studies and bring valuable insight about general chemical trends, such as the influence of temperature, as studied in this article. Further work may focus on two directions:

1. Developing the global equilibrium model in order to be able to predict the hydrocarbons (CH_4 and main C_2s) as well;

2. Include complex ash chemistry.

WP2.3 Pyrolysis

Enabling the biocarbon value chain for energy

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.

During these last years, considerable research efforts in CenBio have provided new knowledge about biocarbon production and the factors influencing the yield and properties of biocarbon produced from various biomass resources. The subject gained so much interest that an application for a spin-off project, KPN BioCarb+ (Enabling the biocarbon value chain for energy), was submitted to the Research Council of Norway (RCN) in 2013. The application was successful, got excellent reviews and received full funding from the RCN. Full industry funding for the project was achieved through a number of industry partners covering all parts of the biocarbon value chain for energy. The project will run for 4 years, 2014-2017 with a total budget of 20 MNOK.

The overall objective of this project is the development of new strategies for use of low-grade biomass resources for biocarbon (BC) production and conversion for energy purposes.

Sub-objectives:

- New or improved low-grade biomass harvesting and logistics solutions, with special attention to GROT (branches and treetops) and its fuel properties

- New or improved BC production solutions through development or improvement of low-grade biomass pretreatment methods, BC production processes and applications and BC logistics solutions

- New or improved BC conversion solutions through development or improvement of BC conversion applications with focus on high energy efficiency and low emissions

- Education of highly skilled candidates within this area and training of user partners

- Monitoring of activities and state-of-the-art within this area and dissemination of knowledge to the user partners, and other interested parties where applicable.

The anticipated results of the project are reduced harvesting and logistics costs for low-grade biomass resources, maximised BC yield and quality in the BC production process and maximised energy efficiency and minimised emissions in the BC end-use applications. Figure 20 shows the BC value chain and BC energy density compared to other fuels.

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Figure 21: The BC value chain and BC energy density compared to other fuels.

See the BioCarb+ webpage http://www.sintef.no/BioCarb/ for further info.

Exchange student from University of Hawaii at SINTEF Energy Research

M.Sc. student Greg Specht from the University of Hawaii at Manoa (USA) worked in the SINTEF Energy Research/NTNU Thermal Energy laboratory for a two-month period in 2013 (6 June – 15 August). Greg was involved in several biomass carbonization studies and the characterization of the produced charcoals. The main aim of Greg's study was to investigate the effects of particle size on final char yield and fixed carbon content in the produced biomass charcoal.

Greg performed the following laboratory studies:

- Proximate and ultimate analysis on raw biomass materials according to American Society for Testing and Materials (ASTM) standards.

- Carbonization behaviors of forest residues through Thermogravimetric Analyzer (TGA) experiments. Char yields of each sample as function of temperature and particle size were obtained.

- Production of charcoal from forest residues (GROT) in a temperature controlled muffle furnace. Char yields of each sample as function of temperature were collected.

- Characterization of charcoal produced from the muffle furnace in terms of fixed carbon content and elemental composition.

- Proximate and ultimate analysis of industrial charcoal sample.

During his stay, Greg learned to operate the TGA, muffle furnace and elemental analyzer in the SINTEF Energy Research/NTNU thermal energy laboratory. He also got experience on characterizing samples according to different standards. His supervisor was SINTEF research scientist Liang Wang. Greg is currently completing his master's thesis in Hawaii, partly based on the experimental results and knowledge obtained in Trondheim.

The work carried out and the results obtained are valuable in the further research work on carbonization in both CenBio and the newly started spin-off project KPN BioCarb+ (Enabling the biocarbon value chain for energy, see previous section for details).

WP2.4 Anaerobic digestion

Bio-methane production is a complex, multi-step process, involving many different microbial species. Fermenting bacteria hydrolyze complex organic compounds into oligomers and monomers. The intermediates are further transformed into acetate, carbon dioxide and hydrogen. The final methanogenesis is conducted by archea.

In 2013, steam explosion pretreatment (cf. Figure 22) has been demonstrated to increase biogas yield from hay. SEM (Scanning Electrons Micrographs) imaging was used to look at the effect of the pretreatment on fiber structure of the biomass. The picture series shown in Figure 23 clearly indicates that the pretreatment rips the fibers apart, making them more accessible to microbial degradation. However, excessive severity in the pretreatment led to degradation of carbohydrates and formation of pseudo-lignin, and consequently reduced the amount of substrate available for biogas production. Thus, this study showed that optimization of biogas yield from hay by using steam explosion is a tradeoff between increased accessibility of fibers and carbohydrate degradation. Optimal conditions of pretreatment enabled an increase in biogas yield of 16 % compared to untreated biomass.

Figure 22: Steam explosion unit. (Photo: Bioforsk)

A better understanding of the microbial community structure and corresponding functions underlying the entire producing process will help to optimize the biogas production in a more controlled manner. Molecular biology provides the possible tool to investigate deeply on the microbial community inside a biogas reactor. In 2013, a 454 barcoding pyrosequencing of 16S rRNA genes (Next-generation DNA sequencing) was employed to study the biodiversity and abundance of microbial composition in 3 biogas reactors (respectively named HIAS, VEAS and TOMB 1).

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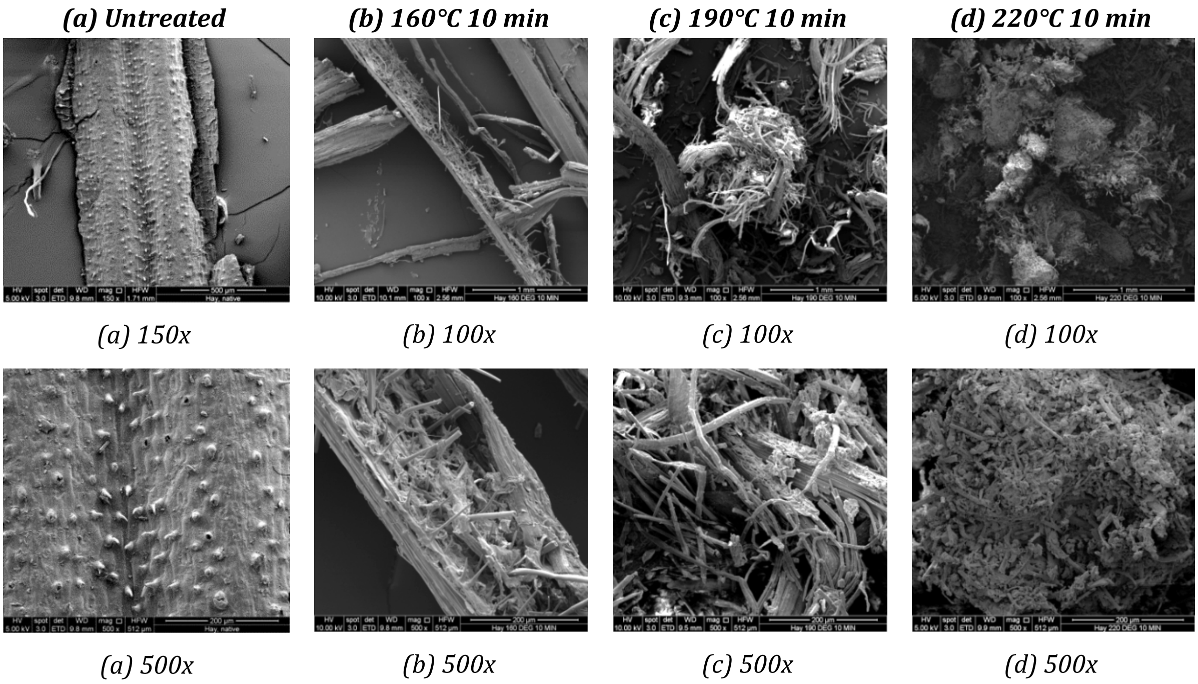

Figure 23: Scanning electron micrographs (SEM imaging) of untreated and steam-exploded hay under magnifications of 100x/150x and 500x. The pretreatment severity increases from left to right.

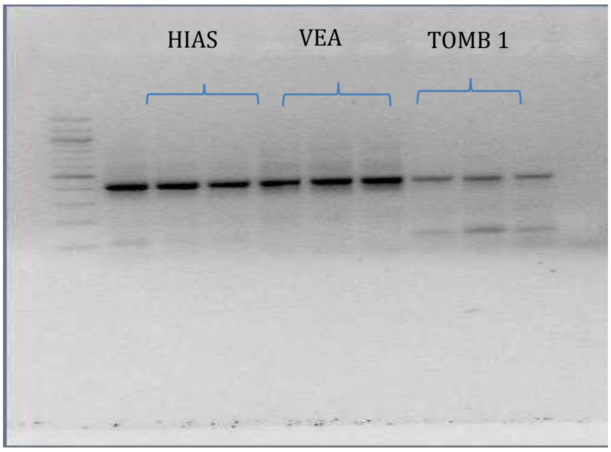

Figure 24: PCR amplified target DNA fragments.

Figure 24 shows the expected DNA fragment (around 400bp) generated by PCR (Polymerase Chain Reaction) using fusion primers. Comparably, the PCR efficiency with sample from the TOMB1 reactor was lower than the other two and complied with primer dimer formation as byproduct.

A plot of rarefaction depicts the diversity profile of the microbial communities in the HIAS and VEAS reactors (cf. Figure 25). With the increase in the sequence reads, the diversity (measured by OTU – see Figure 25 caption) was also rising correspondingly, although none of them was saturated. The microbial community was much more diverse in biogas reactor VEAS than in HIAS.

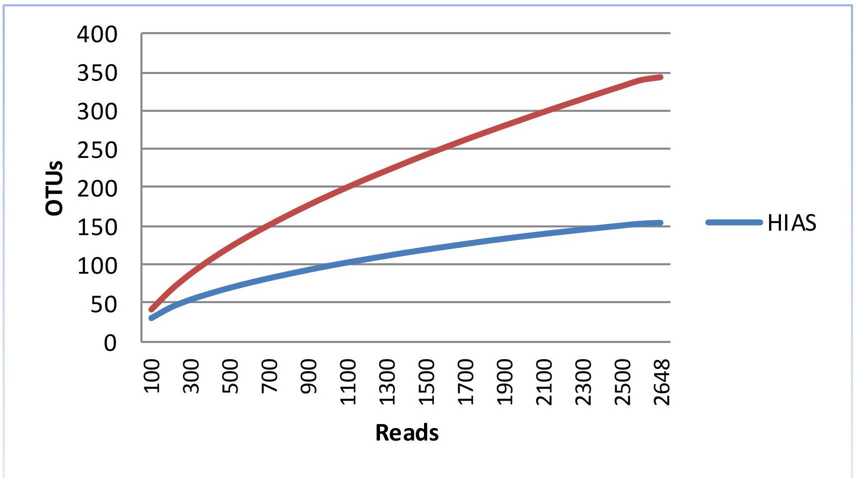

Figure 25: Rarefaction plot of Operational Taxonomic Units (OTU) in different anaerobic digesters.

The results of this preliminary study suggest that molecular tools hold big promise for elucidating community structure in biogas reactors. Changes in community structure may be related to changes in the AD process and, hence, be used to tune operational parameters in biogas plants.

WP2.5 KMB STOP: Torrefaction

In 2013, the CenBio spin-off project KMB STOP (STable OPerating conditions in biomass combustion plants) was completed, except for the PhD study that continues until August 2014.

During the 4 years of torrefaction research in STOP and CenBio, a large amount of research has been carried out. The results, the lessons learned and the prospects of torrefaction have been summarized in the STOP handbook, shown in Figure 26, available at the STOP webpage http://www.sintef.no/Projectweb/STOP/Publications/.

Figure 26: The STOP handbook. (Illustration: SINTEF/Kjetil Strand)

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SP3 Conversion Technologies and Emissions

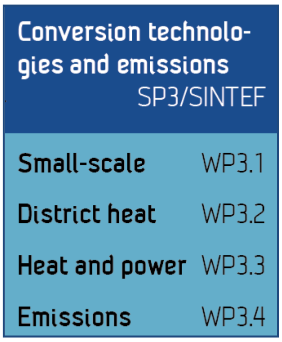

Figure 27: WBS of SP3.

Øyvind Skreiberg

Leader of Conversion Technologies and Emissions

SINTEF Energy Research

(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 Bioenergy Vision 2020 (cf. CenBio Annual Report 2012) are practically and economically feasible, as well as environmentally benign.

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

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

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

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

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

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

Innovations from SP3 are initially expected in the following areas:

- New efficient clean-burning stoves and fireplaces;

- Concepts for ultra-efficient district heating plants, possibly 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 7.5 TWh in 2012), and the use of wood logs in small-scale units and pellets in pellet stoves is expected to increase substantially towards 2020. The goal of this work is to 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.

New wood log gasification concept adaptable for fireplaces

The overall goal with the new concept is to develop a manually operated wood stove based on the principle of gasification with pellet stove emission capabilities, i.e. efficiency up to between 85-95% with the lowest possible weighted particle emissions down to between 0.5-1 g/kg per kg dry wood and measured according to the Norwegian Standard. As far as the

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current knowledge allows, emphasis is also put on the minimization of soot emissions, i.e. particles with high light absorption properties. The new stove should be designed for low and stable, although variable, heat output and be able to operate for extended burning periods of several hours. Figure 28 shows the concept.

Figure 28: New wood log gasification concept adaptable for fireplaces.

WP3.2 District heat

This work package focuses on Waste-to-Energy (WtE) challenges. In 2013, the activities were articulated around these four tasks:

- A presentation based on work carried out in 2012 about the possible uses of fly ash was given at Avfallskonferansen 2013 (Ålesund, 4-6 June 2013)
- A presentation about unusual waste fractions was given at an AvfallNorge Energiutnyttelse seminar (Oslo, 4-5 September 2013)
- A presentation about bottom ash during thermal treatment was also written and is yet to be presented at a suitable workshop/seminar/conference
- Participation in IEA Bioenergy Task 36 (Integrating Energy Recovery Into Solid Waste Management Systems).

Unusual waste fractions

WtE facilities in Norway are often contacted by potential customers (industrial, local, etc.) that want to get rid of large amounts of "unusual" or "not typical" waste fractions. However, facilities' owners/operators often have no or limited knowledge of the physical, chemical and overall thermal properties of these fractions: can they be incinerated safely and efficiently at the plant? What about gaseous emissions and ash composition? To be able to document such knowledge is important in order to be allowed to process waste fractions not specifically mentioned in a plant's authorization.

In the work carried out in WP3.2 in 2013, a selection of unusual waste fractions proposed by CenBio WtE partners were subjected to in-depth literature reviews concerning their properties with focus on combustion behavior. The fractions selected were:

- Car fluff (automotive shredder residues - ASR)
- Flooring
- Fishing net
- Tunnel mat
- Artificial grass
- Dry wall (gypsum)

Not all fractions have been studied to the same extent in the available literature but a large sum of data can usually be found and main combustion trends can be extracted that allow for "bullet points warnings" to be considered by interested WtE facilities. Figure 29 shows a summary table for several materials.

Waste	Materials	Composition	Molecular formula	Source	Property
Gulvbelegg (flooring)	sheet vinyl, vinyl composition tile (VCT), cork (sheet or tile), rubber	Polyvinyl chloride (PVC)	$(C_2H_3Cl)n$	Construction industry waste	High Cl content
Fiskemærer (fishing net)	Mainly nylon	Polypropylene (PP) Polyvinyl chloride (PVC)	$(C_3H_6)n$ $(C_2H_3Cl)n$	Fishing industry	High Cl content
Tunnellmatter (tunnel mat)	Artificial elastomer (polymer)	Synthetic polymers i.e. polychloroprene	C_4H_5Cl	Construction industry waste	
Kunstgress (artifical grass)	Plastic, nylon and rubber	PVC, rubber	Same as above	Construction industry waste	High Cl content
Gips (Dry wall)	Plaster	$CaSO_4$ x $2H_2O$	$CaSO_4$ x $2H_2O$	Construction industry waste	High Ca and S contents

Figure 29: Summary table for some waste fractions.

Bottom ash during thermal treatment

The question addressed in this study can be summarized as follows: how can the ash (physical and chemical) properties/quality be affected by the combustion conditions? In other words, is it possible to affect/change ash properties to, for example, make it easier to re-use? Ash (both bottom and fly ash) final disposal represents a large cost for WtE plants and reducing these costs is the major motivation behind this study.

The presentation first gives a general update about typical MSW composition including the main chemical and physical properties of bottom ash before summarizing briefly the main ash transformations during combustion. In a second section, the work presents current possibilities to affect/improve bottom ash quality. Three main strategies were identified (see Figure 30Figure 30): (1) pre-treatment of solid waste; (2) post-treatment of bottom ash and (3) choice of combustion technology including adjustment/optimization of operating conditions.

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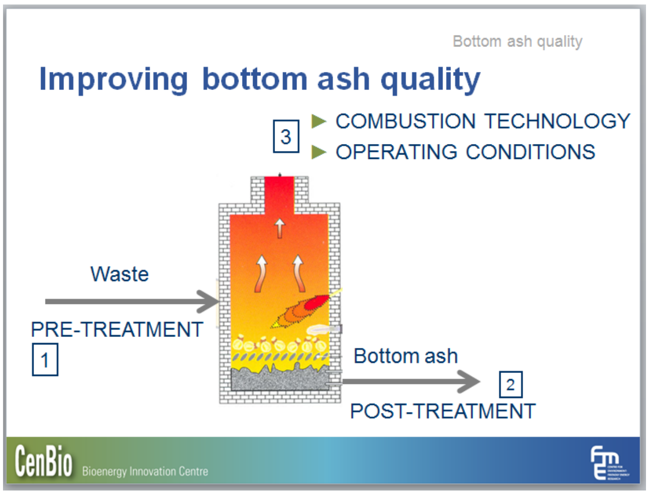

Figure 30: Three main strategies for improving bottom ash quality.

While some options (combustion technology) have to be decided upstream (i.e. for new plants), others (operating conditions) may be implemented in existing facilities.

The presentation summarizes the results from both full-scale and lab-scale studies covering the aforementioned strategies. It can be said that it is possible to affect the bottom ash properties (for example partitioning of Pb) but that may be inconclusive (this might be partly due to the complexity of assessing them experimentally) or conflicting as positive outcomes may be accompanied by negative ones.

All in all, more work is needed to be able to propose innovative alternatives to the costly current situation (bottom ash to landfills and fly ash to special landfills).

IEA Task 36 Integrating energy recovery into solid waste management systems

The 2013 activities include: task meeting #1 in Stockholm in May with a joint workshop with Task 37 (Energy from biogas); task meeting #2 in Milan in November with an SRF workshop. The current topics addressed by the task (2013-2015 triennium) are:

- Small scale energy from waste (population size <100,000)
- Gasification
- Impact of changes in policy on energy and materials recovery
- Mass /energy balance for RDF compared with MSW

In addition, an in-depth report (by RSE, Italy) on the biogenic content of mixed waste is available in the CenBio eRoom.

See http://www.ieabioenergytask36.org/ for further info on IEA Task 36.

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 essential to:

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

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

- The 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.

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

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- The introduction of green certificates in Norway, through the common Swedish-Norwegian green certificate market is an incentive for increased electricity generation from biomass, though, with a 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.

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

Special attention in this WP is directed to implementation of the so-called ChlorOut concept in a full-scale boiler in Jordbro designed for wood fuels, e.g., demolition wood and forest residues (cf. Figure 31). The boiler is a BFB, 63 MW_{th}, 20 MW_{el}, with the steam data 470 °C /80 bar. The implementation is performed as a cooperation between Vattenfall Research and Development AB (VRD) and Vattenfall AB, BU Heat (Heat). The ChlorOut concept consists of IACM, a device for on-line measurements of KCl in the flue gas, and a sulphate-containing additive that converts the alkali chloride to a less corrosive alkali sulphate. The additive applied is often ammonium sulphate (AS) and it can also have an impact on certain other emissions including NOx and CO.

Figure 31: The Jordbro power plant. (Photo: Vattenfall)

The major achievements from 2010 until February 2014 are summarized below. A permanent injection system for ChlorOut has been installed by Heat and the work included planning, engineering, manufacture, assembly and commissioning of the equipment. It is expected that the ChlorOut concept is fully implemented in regular operation of the boiler during the beginning of 2014. Prior to the permanent installation, measurement campaigns were carried out by VRD to optimize the dosage of AS regarding position and quantity, and also verify the effect by short-term measurements. The optimization focused on achieving maximal reduction of KCl, NOx and CO simultaneously. The results obtained during the short-term measurements showed that addition of ammonium sulphate reduced the content of KCl in the flue gases and also chlorine in the deposits. KCl in the flue gas and chlorine in the deposits are indicators for the risk of superheater corrosion. Consequently, the results revealed that injection of AS according to the ChlorOut concept can be applied as a strategy to reduce the corrosion rate of the superheaters in the boiler in Jordbro.

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: half 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.

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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 32) 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 has been going on in 2013. Extensive emission measurements such as those have hardly been carried out earlier at Norwegian BtE plants. This campaign will be carried out spring 2014.

Figure 32: 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. The outcome is a numerical tool that can be used to study NOx emissions and NOx reduction potential from biomass conversion.

In 2013, comprehensive modeling work was started to assess the NOx reduction potential in the multi-fuel reactor using CFD, which is compared with earlier experimental results. This work will be finalized with a journal publication in 2014. Figure 33 shows the reaction section of the multi-fuel reactor and a calculated temperature and NO and CO concentration distribution.

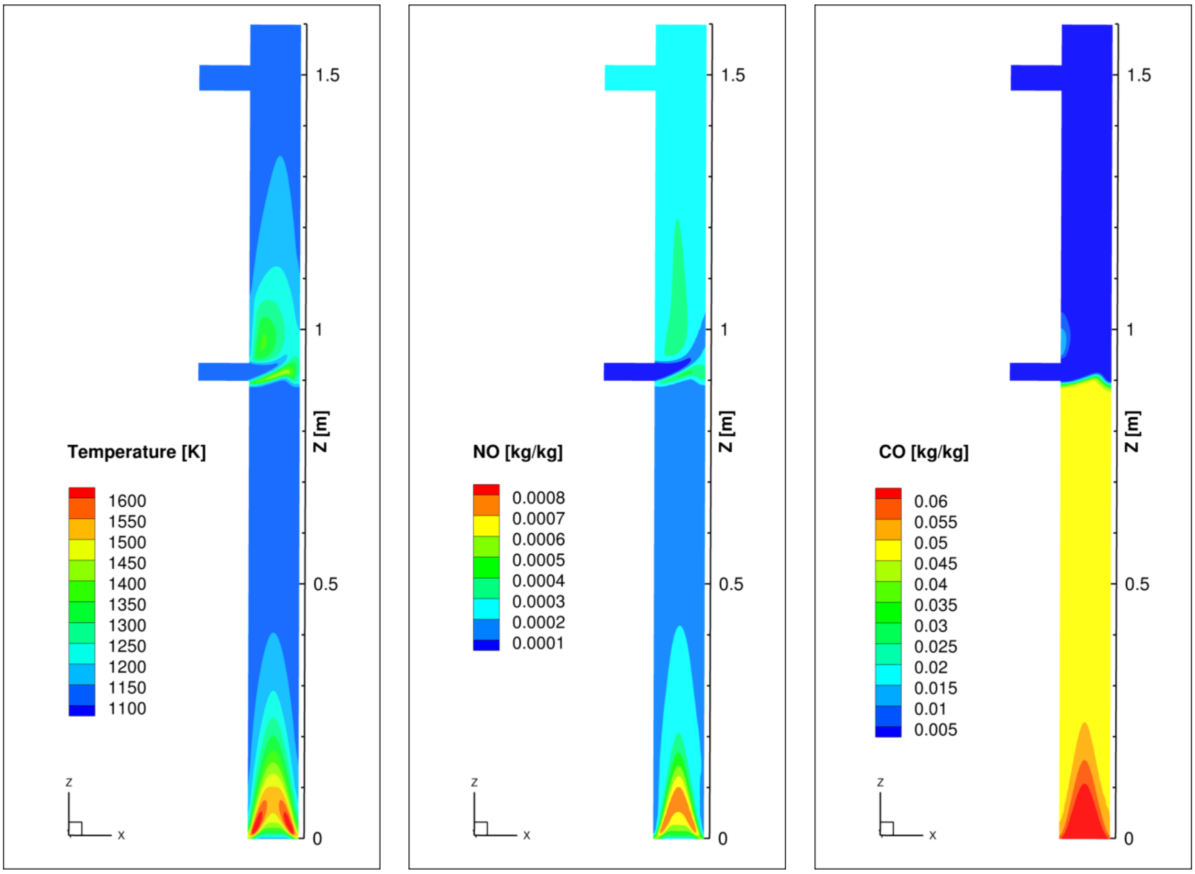

Figure 33: The multi-fuel reactor and a calculated temperature and NO and CO concentration distribution.

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

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

Figure 34: WBS of SP4.

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

WP4.1 Extended Life Cycle Assessment

A key contribution from WP4.1 in 2013 was the completion of Geoffrey Guest's PhD work[20]. He assessed the main possibilities of carbon storage in the bio- and anthroposphere and harmonized the quantification of the corresponding mitigation potential. His study reveals the importance of accurately tracking the temporal dynamics of carbon fluxes to understand the effects that bioenergy and/or biomass storage systems have on the global climate. He developed a scientifically robust methodology for quantifying the climate impacts due to temporary and permanent storage of sustainably regenerated biomass in various carbon pools. He computed characterization factors which can be applied in routine life cycle assessments, and analyzed the trade-off of using biomass for bioenergy directly or at the end of life.

Beyond this, the work on further advancing the methods and metrics for assessment of climate performance bioenergy systems continued with several papers first authored by Francesco Cherubini. This work is central for the forthcoming assessments in SP6.

As a part of the WP4.1 activities CenBio rejoined the IEA Task 38: Greenhouse gas accounting of bioenergy systems. Ryan Bright from NTNU represented Norway at the annual task meeting that was held in Australia.

See http://www.ieabioenergy-task38.org/ for further info on IEA Task 38.

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[20] Geoffrey Guest, *The climate change impacts from biogenic carbon in products across time*, main supervisor: Anders H. Strømman (NTNU)

WP4.2 Ecosystem management

In WP4.2, we focus on the effects of increased biomass removal for bioenergy on the forest ecosystem. Slash contains a large store of nutrients, so its removal could increase the risk of nutrient deficits in the next rotation, leading to lower tree growth. Here we present results for some nutrient concentrations in soil water after harvesting at the field experiments at Gaupen (Hedmark) and Vindberg (Hordaland). Vindberg has a wetter climate and steeper topography than Gaupen. Harvesting at Gaupen took place in March 2009. On the whole-tree plots the slash was piled and the piles allowed to stand until September 2009, when they were removed. At Vindberg, harvesting took place in January 2011 and the slash piles were removed in October 2011.

Changes in the concentrations of NO_3-N and Mg in soil water at 30 cm depth after harvesting are shown in Figure 35 and Figure 36, respectively.

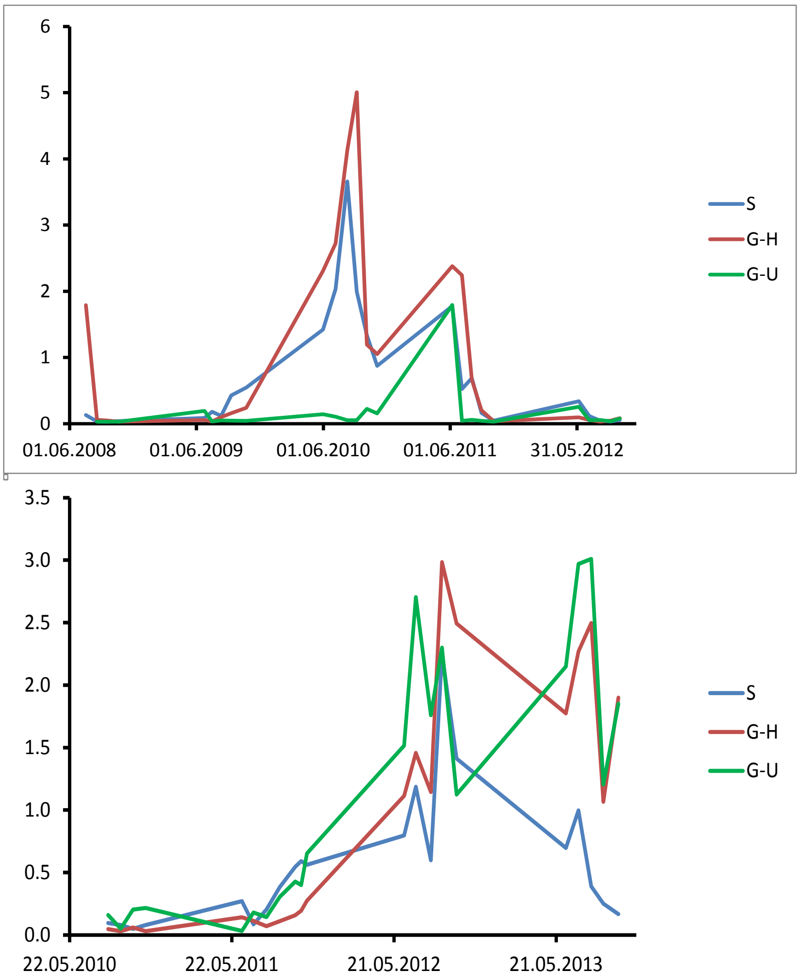

Figure 35: Concentrations of NO_3-N (mg/l) after harvesting at Gaupen (top) and Vindberg (down). S = stem-only harvesting, G-H = whole-tree harvesting where slash was piled, G-U = whole-tree harvesting where slash was removed to form piles.

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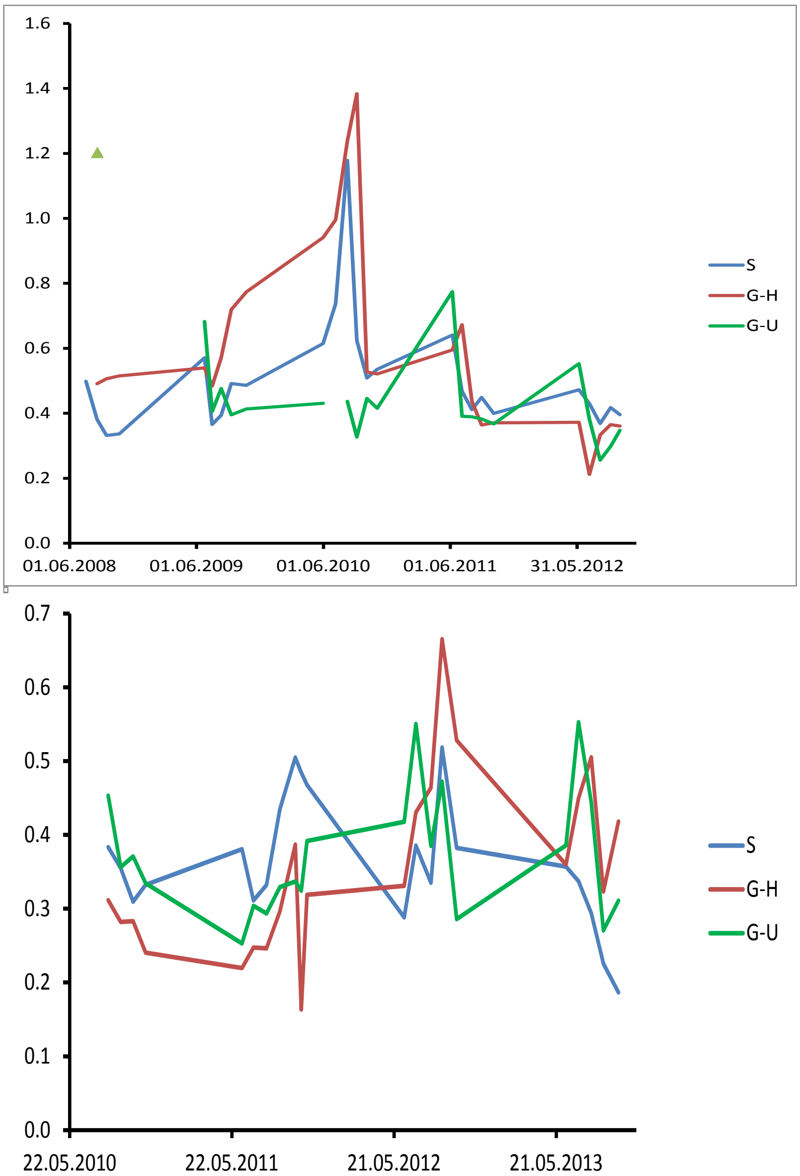

Figure 36: Concentrations of Mg (mg/l) after harvesting at Gaupen (top) and Vindberg (down). S = stem-only harvesting, G-H = whole-tree harvesting where slash was piled, G-U = whole-tree harvesting where slash was removed to form piles.

At Gaupen, nitrate concentrations were very low before harvest (cf. Figure 35), with the exception of the first measurement, for which the high concentration was probably an artifact due to sampler installation. In the first year after harvesting, concentrations remained low. In the second year after harvesting, and after removal of the slash piles, peak concentrations were observed on the stem-only plots and even more on the whole-tree plots where the slash piles had been. Concentrations remained low on the areas of the whole-tree plots where slash had been removed to make the piles. In the third year, smaller peaks were found, and a peak was also observed where slash had been removed. Trends for magnesium (and also for calcium and potassium, not shown) tended to resemble those for nitrate, with peak concentrations in the second year after harvesting (cf. Figure 36). The increased nutrient concentrations observed were probably due to decomposition, leaching and mineralisation of slash, in particular needles, and soil organic matter under slash. Even where slash piles had been removed, it is likely that more nutrients would be available, for example from needles fallen from the piles. Where slash had been removed directly after harvesting in order to form piles, a lower nutrient input would be likely, resulting in lower concentrations.

At Vindberg, the results were less clear-cut. For nitrate, peak concentrations appeared after all treatments in the second year after harvesting, while in the third year peak concentrations were not observed for the stem-only harvesting plots (cf. Figure 35). Similar results were seen for magnesium (cf. Figure 36). These results suggest differences in the decomposition patterns at Vindberg, possibly due to a moister climate, although a complicating factor might be that the higher precipitation and the steeper topography at Vindberg could lead to surface or near-surface downhill water flowpaths with consequent mixing of water from different sources.

It is important to point out that the results from Gaupen suggest that increased concentrations of nutrients in soil water after harvesting are only temporary, and that after a few years the concentrations return to pre-harvesting levels.

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

Competition between wood biomass and other energy sources

Moiseyev et al.[21] have analyzed the effects of different coal, natural gas and carbon emission prices and market situations on the use of wood for electricity and heat production in the European Union plus Norway and Switzerland. The focus is on the competition between the different energy productions and the effect of a tax on CO_2 emissions.

The EFI-GTM (European Forest Institute Global Trade Model), a regionalized partial equilibrium model of the global forest sector with a special emphasis on Europe, was used in the study. The model simulates the behavior of profit maximizing producers and consumers in the global markets for wood and forest products, by simulating the development of competitive market equilibrium over time – i.e. the situation where market prices, traded volumes and supply equals demand for each year and each product.

Table 6 summarizes the main findings in Moiseyev et al.[21] regarding energy produced from wood biomass in 2030 under a high coal and gas prices scenario. The energy technologies for biomass include combined heat and power (CHP), heat-only and electricity-only.

Table 6: Electricity and heat production and wood biomass used for energy in Europe in 2030 as a function of the CO_2 price given high coal and gas prices. Source: Moiseyev et al.[21]

CO_2 price, €/ton	*Electricity production, TWh*	*Heat production, TWh*	*Wood biomass for energy, mill m^3*
10	73	159	151
40	102	177	200
60	118	180	229
80	119	223	236
100	129	263	256

[21] Moiseyev, A., Solberg, B. & Kallio, A. M. I., *Wood biomass use for energy in Europe under different assumptions of coal, gas and CO_2 emission prices and market conditions.* Journal of Forest Economics, 19 (4): 432-449. (2013)

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Heat-only plants only operate under the lowest CO_2 price with a share of about 7%. CHP dominates also in electricity production. The maximum share for electricity-only plants is about 25% and occurs at a CO_2 price of 60 €/ton.

The major share of the biomass is from low-cost harvest residues, but increasing as the carbon price increases. At the highest CO_2 price the share from industrial wood – i.e. pulp wood – is about 11%.

The share of wood-fired electricity is low (cf. Figure 37). The share is increasing when the CO_2 price increases, though it is still below 6 and 7% for the low and high coal and gas price scenarios, respectively.

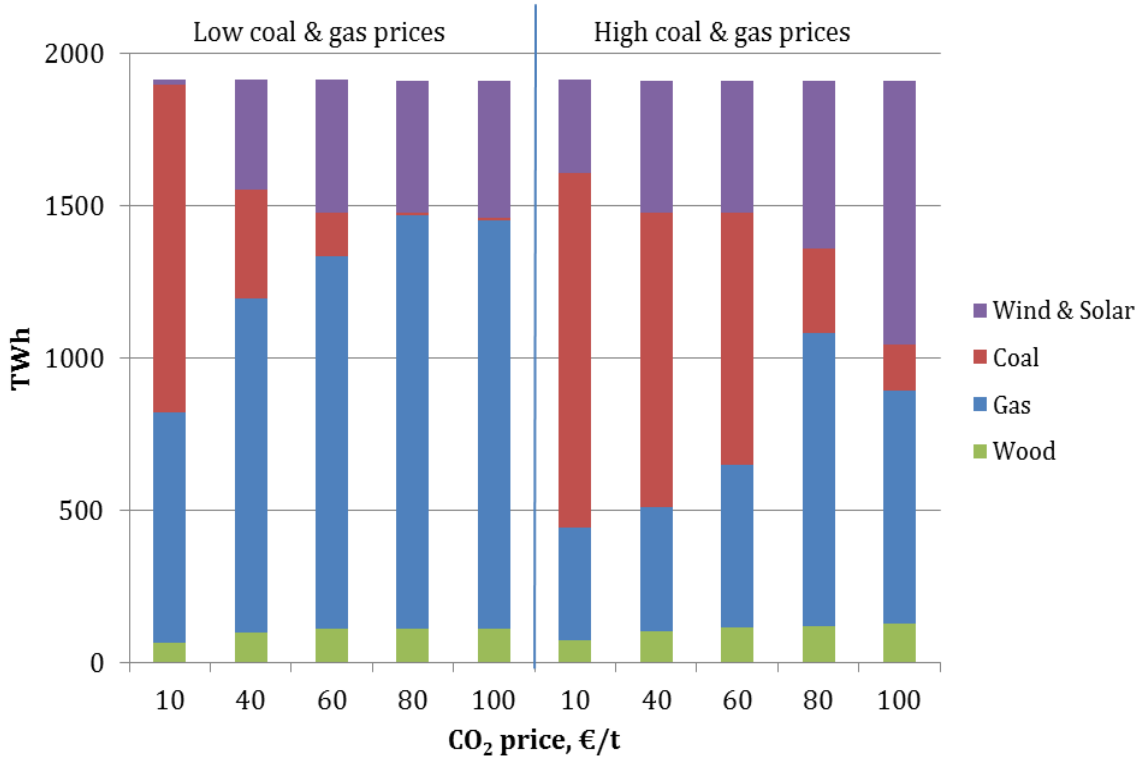

Figure 37: Delivered energy from different sources in 2030. Source: Moiseyev et al.[21]

Under both coal and gas price scenarios, coal power decreases and gas power increases when the carbon price increases. This is due to lower specific emissions (in terms of CO_2/kWh) for electricity production from gas compared to coal.

As can be seen from the table above, the heat production is about twice the electricity production in terms of energy delivered. The heat sector is much smaller than the electricity sector. This means that the share from wood biomass is much larger. Wood-based heat is projected to be up to 31% of the total heat produced by the medium- to large-scale energy sector.

The study has also analyzed the impacts of a subsidy of wood-based electricity production (CHP, electricity-only and co-firing of wood in coal plants). With the assumed 30 €/MWh subsidy and a carbon price of 40 €/t CO_2, the most striking result is that the subsidy helps to maintain coal power's share to a large extent. The increase in the use in wood-fired plants is only modest. It seems that the subsidy can boost the use of wood for energy much more than by only increasing carbon price.

The studied subsidy increases the use of wood for energy, and displaces both coal and gas from the electricity markets. At low carbon prices (e.g. 40 €/t CO_2) wood will mostly displace gas power. This happens because the carbon price is too low to drive coal out of the market. Perhaps this could explain why major European power companies at present are planning to down-size their gas-fired mills. This is contrary to the general strategy by the European Commission that aims at increasing the use of gas and reducing the use of coal in the medium term (until 2030). It will require much higher carbon prices to get coal and gas on a more equal footing. Increased carbon prices and subsidies for wood seem to influence the distribution between coal and gas rather strongly.

Costs of pellets production in Finland, Germany, Norway, Sweden and USA

Trømborg et al.[22] have analyzed the pellets markets in Finland, Germany, Norway, Sweden and USA. The emphasis is on how domestic market prices for pellet production factors, as well as domestic market prices for pellets, vary among the countries. The analysis is based on two model plants: one representing common technologies for small scale pellet production (20 000 t/year) and the other representing large scale production (120 000 t/year). While the first model is based on dry residues from saw mills, the large scale model uses a combination of dry and wet biomass. The economic performance of the two model plants is analyzed for the five countries using country-specific information on production costs and prices.

There are rather large differences between the five countries (see Table 7). Most notably is the rather larger difference in average mill size. Norwegian mills are on average significantly smaller than in the four other countries. We also see that market price for pellets was about 27% higher in Germany compared to Norway in 2009.

Table 7: Characteristics of the analyzed pellet markets in 2009. Source: Trømborg et al.[22]

Country	Production, ton	Domestic consumption, ton	Market price, €/ton[a]	Average production, ton/mill
Finland	290 000	188 000	170	10 741
Germany	1 600 000	1 100 000	193	39 024
Norway	46 500	43 000	152	5 813
Sweden	1 576 000	1 958 000	166	43 778
USA	4 400 000	4 150 000	161	51 765

[a] *Bulk deliveries, excluding VAT.*

Figure 38 shows the estimated production costs for pellets by country and technology. The total production costs vary between 119 and 160 €/t including domestic transport. The production costs for both scales (dry and wet line) are similar in all countries. Overall production costs are significantly lowest in the US due lower feedstock costs. In Europe, Finland has somewhat lower production costs than the other countries. Looking at the cost structure, about 60% of the total costs are expenses for feedstock and feedstock transport. Labor, energy and capital costs are almost equal and of comparable low importance. Hence, the most effective way to cut production costs and raise profitability is to minimize feedstock

[22] Trømborg, E., Ranta, T., Schweinle, J., Solberg, B., Skjevrak, G. & Tiffany, D. G., *Economic sustainability for wood pellets production – A comparative study between Finland, Germany, Norway, Sweden and the US.* Biomass and Bioenergy, 57: 68-77 (2013)

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costs. Cutting capital, energy or labor costs has comparably small effects. For instance, a 10% reduction in costs except feedstock costs would reduce the total cost by about 4%. Since feedstock cost is the decisive factor, it is comprehensible from a cost perspective that in recent years prominent investments into pellet production have been made in the US or, in case of Norway, are based on feedstock from the US.

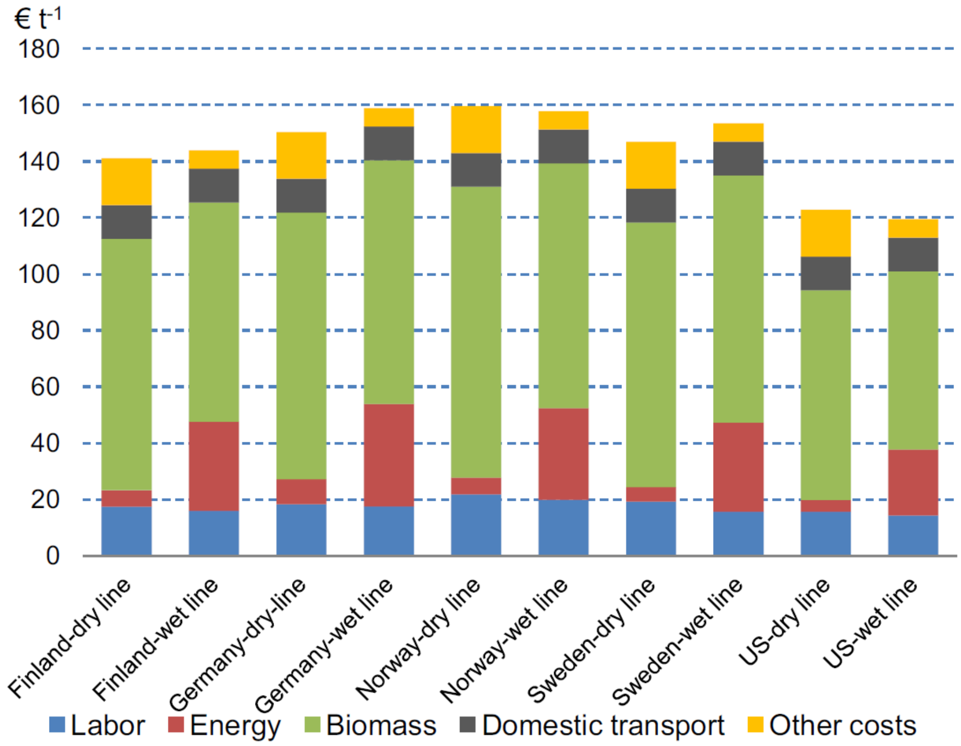

Figure 38: Cost structure of pellet production per country and technology. Dry line is small scale, while wet line is large scale. Source: Trømborg et al.[22]

By comparing the estimated costs in Figure 38 with domestic prices in Table 7, the authors estimate the profitability for the two model mills in each country. In all countries except Norway pellets production is profitable given domestic prices. In Norway, there is roughly a 5 €/t net loss (negative profit) for both scales. This is in line with what we have observed in the Norwegian market.

International prices (in the study, pellets prices delivered in Rotterdam) have been lower than the domestic prices. Using 140 €/t for pellets delivered to the European pellets market and international transportation costs, none of the modeled mills are profitable – with production in USA being closest to profitable.

Trømborg et al.[22] have concluded that increased production in the medium term will probably take place in larger mills based on pulpwood, because pulpwood offers more secure biomass supply compared to dry sawmill residues.

SP5 KNOWLEDGE TRANSFER AND INNOVATION

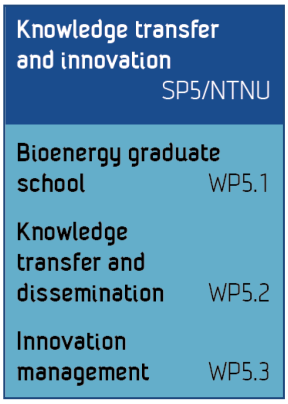

Figure 39: WBS of SP5.

Anders Hammer Strømman

Leader of Knowledge Transfer and Innovation

Norwegian University of Science and Technology

(Photo: NTNU)

The main purposes of SP5 are:

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

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 NMBU 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 2013 (see Table 15).

Approximately 25 PhD candidates have been affiliated with CenBio (see Table 13 and Table 14), though so far, PhD courses in bioenergy have not been developed. The CenBio Graduate School workshop was arranged on 18 January 2012 at NMBU, focusing on climate impact from bioenergy. The level of the PhD candidates affiliated is sufficiently high so that they actively participate in CenBio's workshops as any other researcher.

In 2013, CenBio contributed in planning of the summer school at PhD level in renewable energy, arranged by The Norwegian Research School of Renewable Energy (NorRen). In 2013 in particular, the focus was set on framework conditions for renewable energy.

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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 25) shows the deliverables that were finalized in 2013.

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_5 where 0.1 refers to WP0.1, 5 is selected as the unique number for annual reports while the _5 means the fifth in a series; i.e. annual report for the fifth 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 40 shows the current status of the publications in peer-reviewed journals. The list of journal publications from 2013 is given in the Appendices (see Table 19).

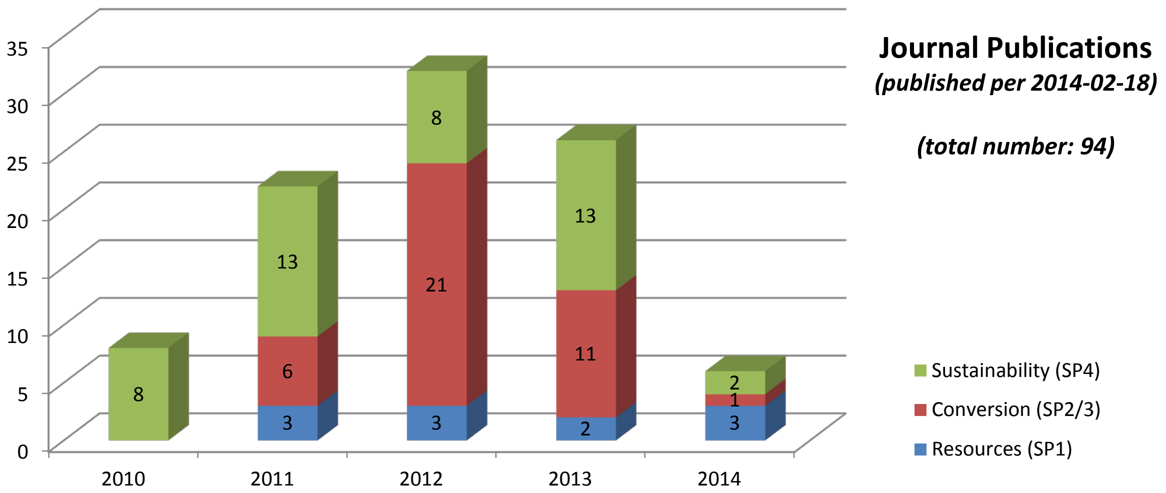

Figure 40: Status of published peer-reviewed articles per year and per research activity.

In 2013, 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 20 and Table 21).

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 24).

Website: www.CenBio.no

The first version of the CenBio website was established and published in June 2009. The website is regularly updated, especially with new public deliverables and news relevant to the Centre. A screenshot of the homepage is shown in Figure 41.

Figure 41: CenBio homepage - www.CenBio.no (per 2014-01-18).

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.

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

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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 three innovation workshops, which were arranged in 2010, 2011 and 2013. A CenBio definition of innovation has been approved, and innovation is included as a guiding star in the annual work plans.

The "List of innovations" (see Table 8) includes more than 30 potential innovations that are identified by now, and we are working systematically to develop these. In this context, patenting and publishing processes are an important issue that has been considered in a separate deliverable.

Nine innovations have so far been completed and fully implemented:

- Afterburner for woodstoves meeting the Norwegian environmental requirements, in close collaboration with the industry 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, based on ash from the user partner Akershus Energi AS, licensed to Herremyr Gård AS,
- Method for on-line syngas calorific value measurement that allows continuous monitoring is developed by Energos and equipment is installed at a commercial plant.
- Firewood calculator. A new method is developed that sets the prize of firewood based on energy content which is the parameter of interest for the customer, instead of volume which has been the previous/current practice.
- Bio bottom ash as raw material for manufacturing of Portland Cement is a concept developed that will stretch the raw material resources (calcium carbonate) and reduce the cement plant CO_2 emissions.

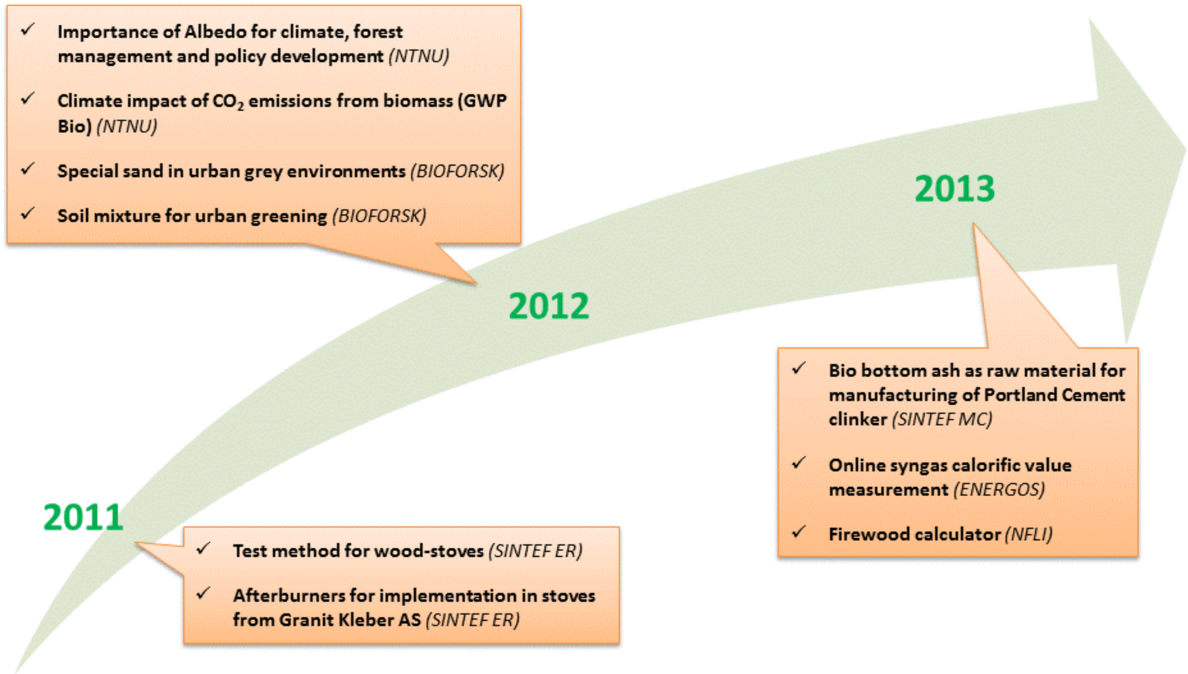

Figure 42: CenBio innovations completed since the beginning of the Centre.

Table 8: List of innovations within CenBio (per 31 December 2013).

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*
I1.2.5	Spreadsheet tool for strategic supply chain configuration	NFLI	Concept	*In progress*
I1.3.1	Tailored fuel mixtures	SINTEF-ER	Product	*In progress*
I1.3.2	Tailored chip deliveries	NFLI	Concept	*In progress*
I1.3.3	**Firewood calculator**	**NFLI**	**Service**	***Completed***
I1.4.1	New fertilizers	BIOFORSK	Product	*In progress*
I1.4.2	Organic NKP fertilizer	BIOFORSK	Product	*In progress*
I1.4.3	**Special sand**	**BIOFORSK**	**Product**	***Completed***
I1.4.4	**Soil mixture**	**BIOFORSK**	**Product**	***Completed***
I1.4.5	**Bio bottom ash as raw material for manufacturing of Portland Cement**	**SINTEF-MC**	**Concept**	***Completed***
I2.1.1	Additives and fuel mixing procedures	SINTEF-ER	Concept	*In progress*
I2.1.2	Reduced emissions of NOx and particulate matter	SINTEF-ER	Concept	*In progress*
I2.1.3	Smart fuels	SINTEF-ER	Concept	*In progress*
I2.2.1	**On-line syngas calorific value measurement**	**ENERGOS**	**Technology**	***Completed***
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*

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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			

Bioenergy Innovation Awards

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

In 2011, the first BIA awarded SINTEF Research Scientist Edvard Karlsvik for his innovative work with combustion technology for residential woodstoves. In 2012, the second BIA awarded Cambi AS, one of the CenBio partners, for their innovative biogas production process for biomass from waste and sewerage, which is implemented in many plants world-wide.

The BIA 2013 was awarded during the CenBio Days 2013 (10-11 April 2013 in Trondheim), to Sølor Bioenergi. Exclusively using contaminated timber as energy source in their 10 MW combined heat and power (CHP) plant, Solør Bioenergi 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.

Figure 43: Left: Ragnhild Solheim and Nils Røkke announce the winner of the BIA 2013 (Photo: Mette Kjelstad/SINTEF). Centre: Hans M. Moss, General Manager of Solør Bioenergi (Photo: Solør Bioenergi). Right: Solør Bioenergi plant in Kirkenær (Photo: Solør Bioenergi).

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

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SP6 Value Chain Assessment

Anders Hammer Strømman

Leader of Value Chain Assessment

Norwegian University of Science and Technology
(Photo: NTNU)

Figure 44: WBS of SP6.

SP6 aims at integrating a wide array of expertise and knowledge matured within CenBio along with detailed datasets generated from the other SPs into a holistic environmental assessment of bioenergy value chains.

This goal requires a thorough and detailed assessment of the existing bio-energy chains as well as of the possible future options (cf. Figure 45). This research is essential to provide sustainable directions for the national goal of doubling bioenergy production by the year 2020.

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

- Identification of the environmental and economic characteristics of current individual Norwegian bioenergy value chains (individual performance).

- Identification of the total overall environmental and economic characteristics of the current Norwegian bioenergy system (total performance).

- Identification of the environmental and economic characteristics of prospective novel individual Norwegian bioenergy value chains (individual performance).

- Identification of the total overall environmental and economic characteristics of alternative scenarios for different prospective Norwegian bioenergy systems (total performance).

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

- Establishment of a cooperative and interactive network among all research and user partners to start up SP6 activities

- Identification of the most suitable methodological approach for the environmental assessment of the single value chains and of the Norwegian bioenergy system

- Dialogue and discussion on harmonization of LCA and cost assessment methods

- Input parameters and data collection in a standardized data formats for the various chain segments
- Interaction with other SP6 partners to perform data collection, compilation, and harmonization
- Analysis of environmental attributes of different bioenergy chains
- One researcher has been employed to support scientific and administrative tasks in SP6
- Several meetings have been carried out with all partners to ensure the maximum level of interaction and cooperation within SP6

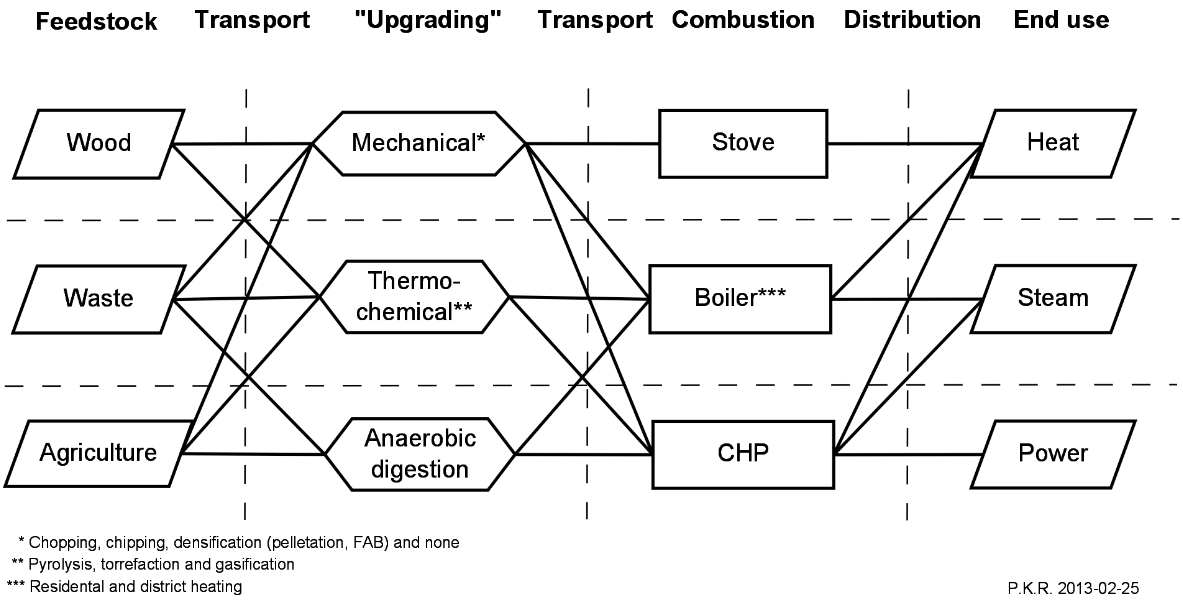

Figure 45: Value chains seen as combinations of research activities from CenBio.

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

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

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Main activities performed by SINTEF-ER on CHP/District Heating

- A classification of biomass-to-energy and waste-to-energy plants was agreed upon (according to national regulations)

- Appropriate process flow diagrams have been made, pointing out main differences between plant categories

- Taking into account direct feedback from the industry, a plant survey form was elaborated and sent out to the user partners. The requested information encompassed several plant specific information and data (e.g., size and location of the plant, production, emissions, costs, fuel type, consumables etc.).

- Survey follow-up

- Based on information collected in the survey, mass and energy balances have been performed (plant process models)

- The initial plant process models have resulted in calculations on the thermal conversion, heat recovery steam generation, district heat and power production, and flue gas cleaning/emissions

- A consultant has been hired to collect information from small biomass-to-energy plants, so to better represent this segment in CenBio

- A database with information on Norwegian waste and biomass conversion plants was initiated

Summary of the activities performed by SINTEF-ER on wood stoves

- Combustion of wood logs in wood stoves is an important biomass consumer and emission source in Norway. A previous study has estimated the contribution of different emissions from wood stoves to selected environmental and health impact categories. The results from this work also show the importance of having specific/representative emission factors for different emission compounds from wood stoves, both traditional (old technology pre 1998) and modern wood stoves.

- In 2013, the CenBio SP6 work on wood stoves concentrated on emission factors, with the aim of checking the validity of the existing emission factors used in the Norwegian national emission inventory. The main goal is to perform experimental analysis and literature review to either confirm the existing emission factors or suggest improved factors that are more representative for the current Norwegian firing habits.

- So far, the conclusion is that there is a need for updating some of the emission factors, an update that can significantly change the relative contribution of different emission compounds to different environmental and health impact categories and their relative importance.

- In addition, wood stove efficiencies have been evaluated, showing that particularly for traditional (old technology) wood stoves there is a need for increasing the efficiency currently used. This work will be finalized in 2014, also collecting materials and costs data needed for a complete value chain analysis of the wood stove segment in Norway.

INTERNATIONAL COOPERATION

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

The cooperation between CenBio researchers and external (non-CenBio) actors in bioenergy research has always been a priority for the Centre to stand on the international scene. Figure 46 shows the status of journal publications resulting from collaborative work involving non-CenBio partners, since the start of the Centre.

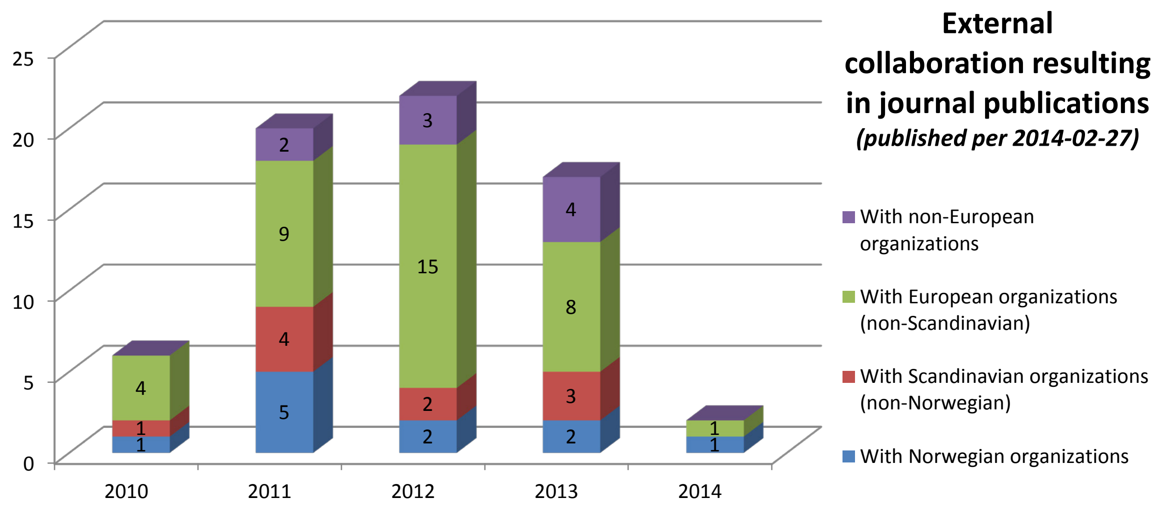

Figure 46: Status of external collaborations resulting in journal publications within CenBio.

International institutions

The international institutions listed below took part in collaborative research activities with CenBio in 2013:

- University of Copenhagen (DK)
- Åbo Akademi (FI)
- METLA - Finnish Forest Research Institute (FI)
- Lappeenranta University of Technology (FI)
- Johann Heinrich von Thünen-Institute (vTI) (GE)
- Hungarian Academy of Sciences (Hungary)
- School of Biosystems Engineering (IR)
- Landcare Research (New Zealand)
- Swedish University of Agricultural Sciences (SLU) (S)
- University of Belgrade (Serbia)
- University of Hawaii at Manoa (USA)
- University of Minnesota (USA)
- Oregon State University (USA)

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The fruitful cooperation with Professor Michael J. Antal, Jr. from University of Hawaii has continued in 2013. 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 is present at SINTEF Energy Research three months per year.

International conferences

CenBio has been presented at a number of international conferences in 2013. Details are listed in Table 21.

Participation in Tasks from the International Energy Agency (IEA)

Various IEA Bioenergy tasks with involvement of CenBio staff are listed in Table 9.

Table 9: 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/ Roald Sørheim
Task 38	*Greenhouse gas balances of biomass and bioenergy systems*	01 NMBU + 03 NTNU SP4	Anders Strømman
Task 40	*Sustainable International Bioenergy Trade - Securing Supply and Demand*	01 NMBU WP4.3	Birger Solberg Erik Trømborg
Task 43	*Biomass feedstocks for energy markets*	05 NFLI WP1.1	Simen Gjølsjø

RECRUITMENT

The research within CenBio is mainly performed by permanent employees with the research institutes and the universities (see Table 10). In some cases, doctoral and postdoctoral researchers have been recruited to perform research within CenBio. A list of such researchers is given in Table 12, Table 13 and Table 14.

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APPENDICES

A. Personnel

Key Researchers

Table 10: Key staff members who spent more than 10% of their time in CenBio in 2013.

Name	Affiliation	Univ. degree	Sex	Position within own organization	% of full time
Odd Jarle Skjelhaugen	NMBU	PhD	M	*Centre Director, Professor*	30%
Tron Haakon Eid	NMBU	PhD	M	*Professor*	10%
Even Bergseng	NMBU	PhD	M	*Research Scientist*	15%
Svein Jarle Horn	NMBU	PhD	M	*Professor*	90%
Alexander Moiseyev	NMBU	PhD	M	*Research Scientist*	100%
Per Kristian Rørstad	NMBU	PhD	M	*Research Scientist*	25%
Birger Solberg	NMBU	PhD	M	*Professor*	10%
Marie Bysveen	SINTEF-ER	PhD	F	*Executive vice-president*	10%
Berta Matas Güell	SINTEF-ER	PhD	F	*Research Manager*	10%
Einar Jordanger	SINTEF-ER	PhD	M	*Quality- and Security Manager*	50%
Alexis Sevault	SINTEF-ER	PhD	M	*Research Scientist*	50%
Øyvind Skreiberg	SINTEF-ER	PhD	M	*Senior Research Scientist*	25%
Morten Seljeskog	SINTEF-ER	PhD	M	*Research Scientist*	10%
Mette Bugge	SINTEF-ER	MSc	F	*Research Scientist*	20%
Roger Khalil	SINTEF-ER	PhD	M	*Research Scientist*	20%
Michaël Becidan	SINTEF-ER	PhD	M	*Senior Research Scientist*	30%
Judit Sandquist	SINTEF-ER	PhD	F	*Research Scientist*	10%
Liang Wang	SINTEF-ER	PhD	M	*Research Scientist*	60%
Pier Paolo Francese	NTNU	PhD	M	*Research Scientist*	30%
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 K. Haraldsen	Bioforsk	PhD	M	*Senior Research Scientist*	25%
Roald Sørheim	Bioforsk	PhD	M	*Research Scientist*	15%
Uno Andersen	Bioforsk	MSc	M	*Research Scientist*	10%
Nicholas Clarke	NFLI	PhD	M	*Senior Research Scientist*	10%
Leif Kjøstelsen	NFLI	MSc	M	*Research Scientist*	10%
Helmer Belbo	NFLI	PhD	M	*Research Scientist*	20%
Eirik Nordhagen	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-MC	PhD	M	*Research Scientist*	20%
Tomas Leffler	VRD	MSc	M	*PhD candidate*	10%
Åsa Astervik	VRD	MSc	F	*Research Scientist*	10%

Visiting Researchers

Table 11: Visiting researchers from other countries in 2013.

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
Gregory P. Sprecht	*PhD Student*	University of Hawaii at Manoa	USA	3 months
Trung Ngoc Trinh	*PhD Student*	Technical University of Denmark (DTU)	Denmark	2 months
Susanne V. Jørgensen	*Research Scientist*	Technical University of Denmark (DTU)	Denmark	1 month

Postdoctoral Researchers

Table 12: List of postdoctoral researchers working in the Centre in 2013.

Name	Affiliation	Source of funding	Sex	Nationality	Period worked in the Centre
Xiaoke Ku	NTNU	CenBio	M	*Chinese*	2012 – 2013

PhD students

A database on PhD students working on issues related to CenBio's research activities has been established; see Table 13 and Table 14.

Table 13: PhD students, both CenBio-funded and associated, working within CenBio in 2013.

Name	Sex	Affil.	Topic/Research area	Source of funding	Period in the Centre
Paulo Borges	M	NMBU	*Develop decision support systems for long-term analyses of biomass*	CenBio WP1.1	2010-11 2014-02
Geoffrey Guest	M	NTNU	*Hybrid life cycle analysis of solid bio-fuel systems*	CenBio WP4.1	2009-08 2014-01
Dmitry Lysenko	M	NTNU	*Combustion modelling*	CenBio WP2.1	2010-03 2014-03
Aaron Smith	M	NMBU/ NFLI	*Develop models and methods for quantification of birch biomass*	CenBio WP1.1/ RCN	2010-08 2014-07
Eva Brod	F	NMBU/ Bioforsk	*Organic waste resources and wood ash as fertiliser, phosphorus flows and stocks in the food system*	50% CenBio / RCN	2012-05 2016-04
Quang Vu Bach	M	NTNU	*Thermal pre-treatment of biomass and biomass residues*	20% CenBio / STOP	2011-08 2014-08
Silje Skår	F	NMBU	*Ecological modelling related to increased biomass removal in forests in Norway*	25% CenBio / RCN	2009-12 2013-12
Shuling Chen Lillemo	F	NMBU	*Bioenergy market*	RCN	2008-08 2013-06
Maria M. Estevez	F	NMBU	*Optimization of biogas production (From biomass to biogas project)*	RCN	2009-12 2013-06

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Kristian Fjørtoft	M	NMBU	*Biogas optimization in farm scale biogas plants*	NMBU	2009-08 2013-05
Zarah Forsberg	F	NMBU	*Characterization and directed evolution of carbohydrate-binding modules (CBMs) for biomass conversion*	RCN	2010-01 2013-12
Geir Skjevrak	M	NTNU	*Wood pellets utilized in the commercial and residential sectors – an in-depth study of selected barriers for increased use*	STATOIL/ own funding	2006-01 2013-12

Table 14: Completed PhD theses linked to the Centre (per 2014-02-28).

Year	Name	Sex	Title of thesis	Adviser	Institution granting degree
2011	Hanne K. Sjølie	F	*Analyses of the use of the Norwegian forest sector in climate change mitigation*	Birger Solberg	NMBU
2011	Ryan Bright	M	*Environmental Systems Analysis of Road Transportation Based on Boreal Forest Biofuel: Case Studies and Scenarios for Nordic Europe*	Anders H. Strømman	NTNU
2011	Kavitha Pathmanathan	F	*Granular-bed Filtration Assisted by Filter Cake Formation: Advanced Design and Experimental Verification*	Johan E. Hustad	NTNU
2011	Helmer Belbo	M	*Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees*	Rolf Björheden	Linnaeus University, Sweden
2012	Tore S. Filbakk	M	*Fuel quality of forest biomass intended for chips and pellets: the influence of raw material characteristics, storage and handling*	Olav Høibø	NMBU
2012	Dhandapani Kannan	M	*Study of Second Generation Biofuels in Internal Combustion Engines*	Johan E. Hustad	NTNU
2012	Ehsan Houshfar	M	*Experimental and numerical studies on two-stage combustion of biomass*	Terese Løvås	NTNU
2012	Liang Wang	M	*Effect of Additives in Reducing Ash Sintering and Slagging in Biomass Combustion Applications*	Johan E. Hustad	NTNU
2013	Maria M. Estevez	F	*Improving the anaerobic digestion of lignocelluloses and organic wastes: effects of steam explosion, co-digestion and digestate recirculation*	John Morken	NMBU
2013	Shuling Chen Lillemo	F	*Consumers and bioenergy: the effects of behavioural factors on households' heating consumption choice in Norway*	Mette Vik	NMBU
2013	Geir Skjevrak	M	*Wood pellets utilized in the commercial and residential sectors – an in-depth study of selected barriers for increased use*	Johan Einar Hustad	NTNU
2014	Geoffrey Guest	M	*The climate change impacts from biogenic carbon in products across time*	Anders H. Strømman	NTNU
2014	Dmitry Lysenko	M	*On numerical simulation of turbulent flows and combustion*	Ivar S. Ertesvåg	NTNU

Master degrees

Both NTNU and NMBU were providing courses on Bioenergy at Master level in 2013. Some details about the master's level courses in place in 2013 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 students in 2012, 34 in autumn 2013.
Activities:	Class lectures with four sets of home exercises, combined with one thermal lab and several training sessions on process simulation to support the term paper dealing with bioenergy system analysis.

Course:	**NMBU – FORN310: Bioenergy – Resources, Profitability and Solutions**
Level:	Master, 5.0 credits
Objective:	The course should provide an in-depth understanding of the economics of bioenergy use and impacts on the carbon cycle and climate of bioenergy production. In addition, the course should provide insights in technologies for bioenergy production.
Frequency:	Annually, next one in spring 2014.
Students:	In Spring 2013, 31 students took the exam.
Activities:	Class lectures with sets of home exercises, combined with independent study.

Course:	**NMBU – SKOG310: Nordic Forestry and Forest Research**
Level:	Master, 10.0 credits
Objective:	This course is designed for exchange students from outside Norway wishing to learn about forestry and forest research in Norway and the other Nordic countries. Students will learn about: - The natural and socio-economic conditions for forestry in the Nordic countries and the forestry practices that are special to that region; - Current research results related to forest management from NMBU and other Nordic forest research institutes.
Frequency:	Even years, next in autumn 2014.
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.

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Table 15: M.Sc. theses in the Centre in 2013.

Name	Sex	Title of thesis	Adviser	Institution
Miguel Valcuende Sillero	M	*High-throughput experiments for direct liquefaction of biomass in hydrothermal media*	Khanh-Quang Tran	NTNU
Syed Alizeb Hussain	M	*CFD modelling for direct liquefaction of biomass in hydrothermal media*	Khanh-Quang Tran	NTNU
Heidi Ødegård Berg	F	*Comparison of conversion pathways for lignocellulosic biomass to biofuel in Mid-Norway*	Terese Løvås	NTNU
Monica Kviljo	F	*Climate change impacts of co-firing forest biomass from Russia with coal in the Russian power sector*	Anders H. Strømman	NTNU

B. Accountancy

A detailed accounts report for 2013 was submitted to RCN in January 2014. The main financial figures are repeated in this annual report.

Budget

Table 16 shows the anticipated overall budget for CenBio over eight years. The total costs are estimated at NOK 266.352 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 2013 was NOK 33.520 million, while the final reported costs for 2013 added up to NOK 30.072 million.

Table 16: CenBio overall budget.

(MNOK)	*Actual*	*Actual*	*Actual*	*Actual*	*Actual*	*Budget*	*Plan*		
Total	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
266.352	27.738	38.594	39.291	38.012	30.072	30.733	28.960	28.960	3.991

Accounts 2013

Total costs reported from the partners in 2013 amounts to NOK 30.072 million, of which NOK 27.66 million from Research partners and NOK 2.412 million from corporate partners. The funding from RCN amounts to 49.9% of the total costs.

Funding

Table 17: Funding from various sources 2013.

Source	*NOK million*
The Research Council	15.000
Research partners	9.098
Industry partners	5.975
Public partners	0.000
Total	**30.072**

Costs

Table 18: Reported costs from various partners 2013.

Type	*NOK million*
Research partners	27.660
Industry partners	2.412
Public partners	0
Equipment	0
Total	**30.072**

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C. Publications

All types of publications produced within CenBio in 2013 are listed in Table 25. Below some specific publications are listed in separate tables.

Journal Papers

Table 19: List of journal papers published in 2013.

Title	Author(s)	Lead partner(s)	Journal
Harvest residue potential in Norway – a bio-economic model appraisal	Even Bergseng, Tron Eid, Øivind Løken and Rasmus Astrup	NMBU, NFLI	*Scandinavian Journal of Forest Research*
The Performance of a Residential Pellets Combustor Operating on Torrefied and Raw Spruce and Spruce Derived Residues	Roger A. Khalil, Quang-Vu Bach, Øyvind Skreiberg and Khanh-Quang Tran	SINTEF-ER	*Energy & Fuels*
Modeling of turbulent separated flows using OpenFOAM	D. Lysenko, I.S. Ertesvåg, K.E. Rian	NTNU	*Computers and Fluids*
The effect of peat ash addition to demolition wood on the formation of alkali, lead and zinc compounds at staged combustion conditions	Backman R., Khalil R., Todorovic D., Becidan M., Skreiberg Ø., Goile F., Skreiberg A. and Sørum L.	SINTEF-ER	*Fuel Processing Technology*
Influence of drag force correlations on periodic fluidization behavior in Eulerian–Lagrangian simulation of a bubbling fluidized bed	Xiaoke Ku, Tian Li, Terese Løvås	NTNU	*Chemical Engineering Science*
Large-Eddy Simulation of the Flow Over a Circular Cylinder at Reynolds Number 2 × 10^4	Dmitry A. Lysenko, Ivar S. Ertesvåg, Kjell Erik Rian	NTNU, Computational Industry Technologies	*Flow, Turbulence and Combustion*
Automatic generation of kinetic skeletal mechanisms for biomass combustion	Terese Løvås, Ehsan Houshfar, Mette Bugge and Øyvind Skreiberg	NTNU, SINTEF-ER	*Energy & Fuels*
The smart biofuels of the future	Øyvind Skreiberg, Morten G. Grønli, Michael Jerry Antal Jr.	SINTEF-ER, NTNU, University of Hawaii	*Biofuels*
Is Elevated Pressure Required to Achieve a High Fixed-Carbon Yield of Charcoal from Biomass? Part 2: The Importance of Particle Size	Liang Wang, Øyvind Skreiberg, Morten Gronli, Gregory Patrick Specht, and Michael Jerry Antal, Jr.	SINTEF-ER, NTNU, University of Hawaii	*Energy & Fuels*
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	NMBU	*Bioresource Technology*
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-ER	*Energy & Fuels*

Thermal decomposition kinetics of woods with emphasis on torrefaction	Dhruv Tapasvi, Roger A. Khalil, Gabor Várhegyi, Khanh-Quang Tran, Morten Grønli, Øyvind Skreiberg	SINTEF-ER, NTNU	*Energy & Fuels*
Comparative assessment of wet torrefaction	Quang-Vu Bach, Khanh-Quang Tran, Roger A. Khalil, Øyvind Skreiberg, Gulaim Seisenbaeva	SINTEF-ER, NTNU	*Energy & Fuels*
Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life	Goeffrey Guest, Francesco Cherubini, Anders H. Strømman	NTNU	*Journal of Industrial Ecology*
Bioenergy from forestry and changes in atmospheric CO_2: Reconciling single stand and landscape level approaches	Francesco Cherubini, Goeffrey Guest, Anders H. Strømman	NTNU	*Journal of Environmental Management*
The role of forest residues in the accounting for the global warming potential of bioenergy	Goeffrey Guest, Francesco Cherubini, Anders H. Strømman	NTNU	*Global Change Biology Bioenergy*
Climate impact potential of utilizing forest residues for bioenergy in Norway	Goeffrey Guest, Francesco Cherubini, Anders H. Strømman	NTNU	*Mitigation and Adaptation Strategies for Global Change*
Empirical models of monthly and annual albedo in managed boreal forests of interior Norway	Ryan M. Bright, Rasmus Astrup, Anders H. Strømman	NTNU, NFLI	*Climatic change*
Consistent quantification of climate impacts due to biogenic carbon storage across a range of bio-product systems	Geoffrey Guest, Ryan M. Bright, Francesco Cherubini, Anders H. Strømman	NTNU	*Environmental Impact Assessment Review*
Bioenergy vs. natural gas for production of district heat in district heat in Norway: Climate implications	Francesco Cherubini, Anders Hammer Strømman	NTNU	*Energy Procedia*
Global climate impacts of forest bioenergy: what, when and how to measure?	Francesco Cherubini, Ryan M Bright and Anders H Strømman	NTNU	*Environmental Research Letters*
Biogenic CO_2 fluxes from bioenergy and climate—A response	Francesco Cherubini, Anders H. Strømman, Edgar Hertwich	NTNU	*Ecological Modelling*
Whole-tree thinnings in stands of Scots Pine (Pinus sylvestris) and Norway spruce (Picea abies): Short- and long-term growth results	Bjørn Tveite, Kjersti Holt Hanssen	NFLI	*Forest Ecology and Management*
Economic sustainability for wood pellets production – A comparative study between Finland, Germany, Norway, Sweden and the US	Erik Trømborg, Tapio Ranta, Jörg Schweinle, Birger Solberg, Geir Skjevrak, Douglas G. Tiffany	NMBU	*Biomass & Bioenergy*
A review of recent developments and applications of partial equilibrium models of the forest sector	Gregory S. Latta, Hanne K. Sjølie, Birger Solberg	Oregon State University, NMBU	*Journal of forest economics*

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Wood biomass use for energy in Europe under different assumptions of coal, gas and CO_2 emission prices and market conditions	Alexander Moiseyev, Birger Solberg, A. Maarit I. Kallio	NMBU, METLA	*Journal of forest economics*

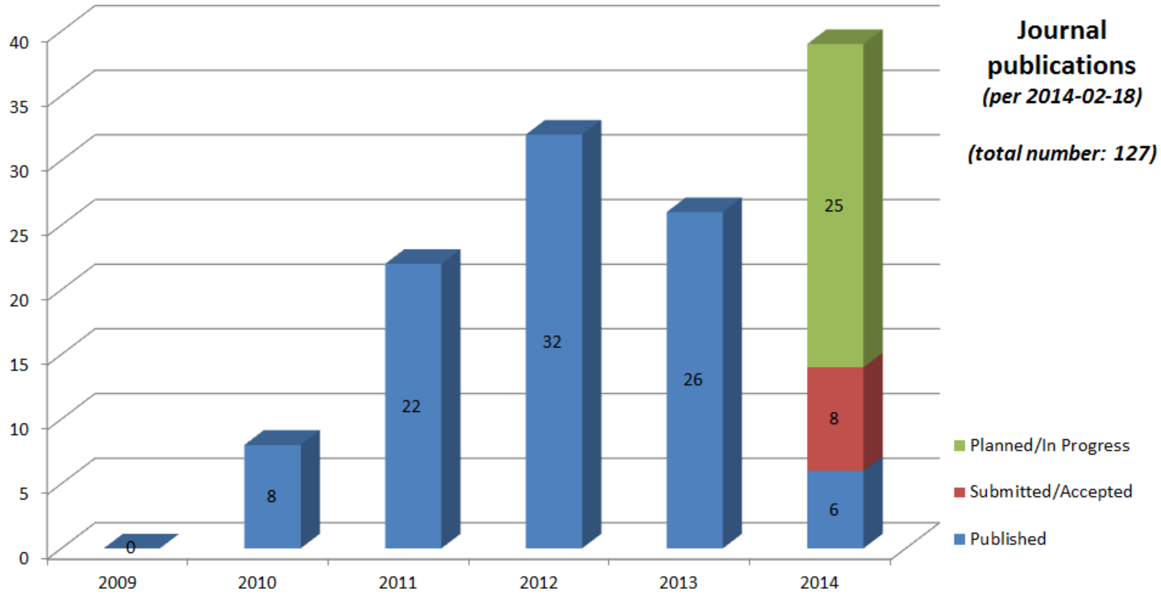

Figure 47: Status of peer-reviewed journal papers published within CenBio.

Published Conference Papers

Table 20: List of conference papers published in 2013.

Title	*Author(s)*	*Lead partner(s)*	*Conference*
Eulerian-Lagrangian Simulation of Wood Gasification in a High-Temperature Entrained Flow Reactor	X. Ku, T. Li, T. Løvås	NTNU	*Proceedings of the European Combustion Meeting 2013*
Effect of torrefaction on pelletability and pellet properties of Norwegian biomass fuels	Nevena Mišljenović, Quang-Vu Bach, Khanh-Quang Tran, Carlos Salas-Bringas, Øyvind Skreiberg	UMB, NTNU, SINTEF-ER	*Proceedings of 21^{st} European Biomass Conference and Exhibition, 3-7 June 2013, Copenhagen, Denmark*
Testing of zeolite and kaolin for preventing ash sintering and fouling during biomass combustion	Liang Wang, Michaël Becidan, Øyvind Skreiberg	SINTEF-ER	*Chemical Engineering Transactions - 16th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction*
Numerical simulation of turbulent flames using the Eddy Dissipation Concept with detailed chemistry	Dmitry A. Lysenko, Ivar S. Ertesvåg, Kjell Erik Rian, Bjørn Lilleberg, Dominik Christ	NTNU	*Seventh National Conference on Computational mechanics, Trondheim, 13-14 May, 2013*

A simplified approach for municipal solid waste gasification modelling	E. Housfar, M. Becidan, P. Lundstrøm and A. Grimshaw	Energos, SINTEF-ER	*Fourteenth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 30 September – 4 October 2013*
Experimental Study of a Single Particle Reactor at Combustion and Pyrolysis Conditions	Houshfar, Ehsan, Wang, Liang, Vähä-Savo, Niklas, Brink, Anders, Løvås, Terese	ENERGOS, SINTEF-ER, NTNU, Åbo Akademi	*Chemical Engineering Transactions - 16th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction*
Influence of wet and dry torrefaction process on biomass to liquid fuel production through Fischer-Tropsch under Norwegian conditions	Rajesh S. Kempegowda, Khanh-Quang Tran, Quang-Vu Bach, Øyvind Skreiberg, Mette Bugge	NTNU, SINTEF-ER	*Proceedings of ICAE2013, Pretoria, 1-4 July 2013*
Pyrolysis kinetics of wet torrefied Norwegian biomass fuels	Quang-Vu Bach, Khanh-Quang Tran, Øyvind Skreiberg	NTNU, SINTEF-ER	*Proceedings of ICAE2013, Pretoria, 1-4 July 2013*
Approaches to soil sustainability in guidelines for forest biomass harvesting and production in forest and plantations	I. Stupak, B. Titus, N. Clarke, T. Smith, A. Lazdins, I. Varnagiryte-Kabasinskiene, K. Armolaitis, M. Peric, C. Guidi	NFLI	*Workshop W6.1 Forest Bioenergy and Soil Sustainability, EuroSoil Congress, 2-6 July 2012, Bari, Italy*

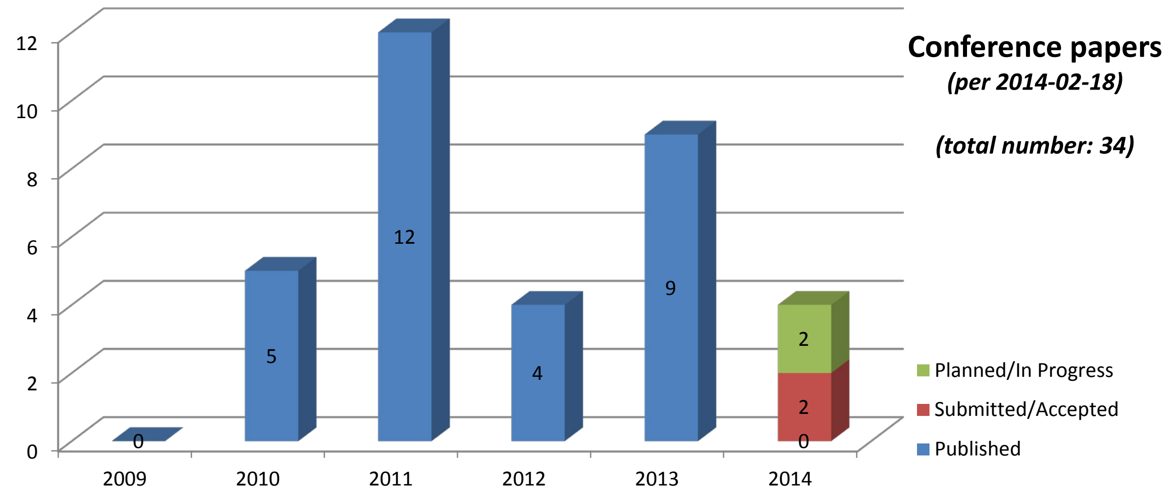

Figure 48: Status of conference papers published within CenBio.

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Conference Presentations

Table 21: List of conference presentations given in 2013.

Title	Author(s)	Lead partner(s)	Conference
Phosphorus case Norway: Focus on organic P-rich waste	Eva Brod, Anne Bøen	Bioforsk	*Wageningen, February 2013*
Hydrothermal pretreatment of kelp biomass for energy applications – a high-throughput screening	Miguel Valcuende Sillero, Quang-Vu Bach, Khanh-Quang Tran	NTNU	*3rd International Conference on Algal Biomass, Biofuels and Bioproducts, 16-19 June 2013*
Advancing Turbulent Combustion Modeling Using the Eddy Dissipation Concept with Detailed Chemistry	Lysenko, D.A., Ertesvåg, I.S., Rian, K.E.	NTNU, Comput. IT	*OSCIC'13, Seventh Open Source CFD International Conference, 24th-25th October, 2013, Hamburg, Germany*
Turbulent combustion modeling using the Eddy Dissipation Concept with detailed chemistry	Lysenko, D.A., Ertesvåg, I.S., Rian, K.E.	NTNU, Comput. IT	*MCS'13, Eighth Mediterranean Combustion Symposium, 9-13 September, 2013, Çesme, Izmir, Turkey*
Testing of zeolite and kaolin for preventing ash sintering and fouling during biomass combustion	Liang Wang, Michaël Becidan, Øyvind Skreiberg	SINTEF-ER	*16th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, 29 September - 2 October 2013, Rhodes, Greece*
Experimental Study of a Single Particle Reactor at Combustion and Pyrolysis Conditions	Houshfar, Ehsan; Wang, Liang; Vähä-Savo, Niklas; Brink, Anders; Løvås, Terese	SINTEF-ER, NTNU, ENERGOS, Åbo Akademi	*16th Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, 29 September - 2 October 2013, Rhodes, Greece*
Attainment of High Fixed-Carbon Yields from Biomass	Liang Wang, Øyvind Skreiberg, Morten G. Grønli, Michael J. Antal Jr	SINTEF-ER, NTNU, University of Hawaii	*Nordic Biochar Seminar in Helsinki, Finland, 14-15 February, 2013*
Is Elevated Pressure Required to Achieve a High Fixed-Carbon Yield of Charcoal from Biomass? The Importance of Particle Size	Michael J. Antal, Jr., Liang Wang, Øyvind Skreiberg, Morten G. Grønli	SINTEF-ER, University of Hawaii, NTNU	*International Symposium held at Osaka University, Japan at the 18th March 2013*
Projet proposal "BioCarb+": Enabling the biocarbon value chain for energy	Øyvind Skreiberg	SINTEF-ER	*SINTEF Meeting, 2013*
Modelling the ecological consequences of whole tree harvest for bioenergy production	Silje Skår	UMB, NFLI	*Annual meeting of the European Geosciences Union in Vienna, April 2013*
Modelling the ecological consequences of whole tree thinning for bioenergy production	Silje Skår	UMB, NFLI	*Seminar "Management effects on environmental services of forest ecosystems: carbon, bioenergy, water and biodiversity", Hveragerdi, Iceland, May 2013*
Environmental impacts of harvesting biomass from the Nordic forests	Nicholas Clarke	NFLI	*Nordic Baltic Bioenergy 2013*

Environmental Services Provided by Forests - an Overview	Nicholas Clarke	NFLI	*Conference "Interdisciplinary Research for Higher Socioeconomic Value of Forests", Riga, Latvia, 10-12 June 2013*
Biogenic CO_2 emissions, changes in surface albedo, and biodiversity impacts from establishment of miscanthus plantation	Jørgensen SV, Cherubini F, Michelsen O	NTNU	*7th International Conference on Industrial Ecology, ISIE. Ulsan, South-Korea, 25 - 28 June 2013*

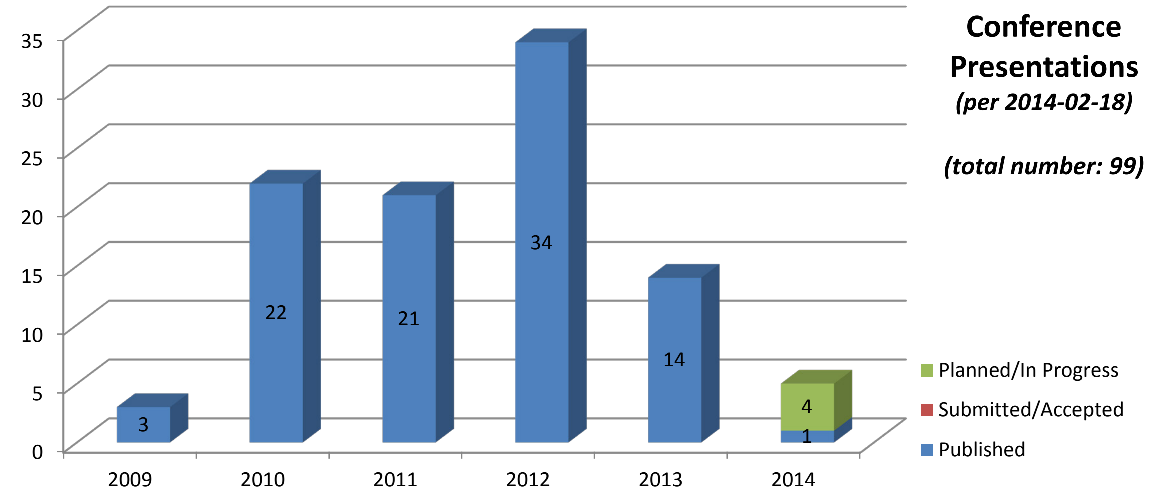

Figure 49: Status of conference presentations performed within CenBio.

Chapters in books

Table 22: List of books with contributions from CenBio published in 2013.

Title	*Author(s)*	*Lead partner*	*Pages*	*ISBN*
STOP: Stable Operating conditions for biomass combustion plants	Øyvind Skreiberg, Roger Khalil, Astrid B. Lundquist	SINTEF-ER	12	978-82-594-3626

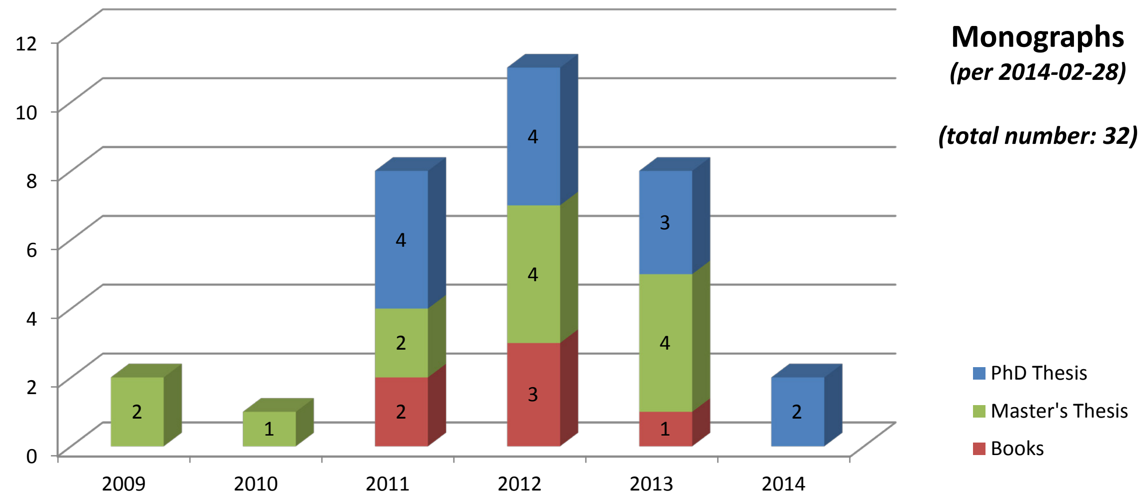

Figure 50: Status of monographs published within CenBio.

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Reports

Table 23: List of reports finalized in 2013.

Title	Author(s)	Lead partner	Class.
Annual Work Plan 2014	Einar Jordanger (+CMT)	SINTEF-ER	*Restricted*
Progress report 1 2013	Einar Jordanger	SINTEF-ER	*Restricted*
Progress report 2 2013	Alexis Sevault	SINTEF-ER	*Restricted*
Accounts Report 2012	Einar Jordanger	SINTEF-ER	*Restricted*
Annual Report 2012	Alexis Sevault	SINTEF-ER	*Public*
Economic sustainability of biomass feedstock supply (IEA joint paper)	Tanja Ikonen, Antti Asikainen, [...], Bruce Talbot	NFLI	*Public*
Supply chain cost analysis of ten alternative chains for high quality wood chip production	Helmer Belbo, Bruce Talbot, Leif Kjøstelsen	NFLI	*Public*
Flis og flisegenskaper - En undersøkelse av brenseflis i det norske flismarkedet	Eirik Nordhagen, Simen Gjølsjø	NFLI	*Public*
Solid biofuels from forest – fuel specification and quality assurance - Inherent properties of Norway spruce biomass in some geographical locations in South Norway	Janka Dibdiakova, Simen Gjølsjø, Liang Wang	NFLI/ SINTEF-ER	*Public*
Efficiency of combined waste resources as N and P fertiliser to spring cereals	Eva Brod, Trond Knapp Haraldsen, Tore Krogstad	BIOFORSK	*Public*
Wood ash in Portland cement clinker	Bjarte Øye	SINTEF-MC	*Restricted*
Plantetilgjengelig forsfor i avløpsslam - Testing av analysemetodikk for tilgjen	Anne Falk Øgaard	BIOFORSK	*Public*
Bioenergy laboratory development 2013	Øyvind Skreiberg	SINTEF-ER	*Restricted*
Optimisation to achieve minimum corrosion rate and maximum NOx and CO reduction	Åsa Astervik, Håkan Kassman	VRD	*Restricted*
Short term measurements 1 and 2	Åsa Astervik, Håkan Kassman, Annika Stålenheim	VRD	*Restricted*
NOx formation - Initial CFD study	Mette Bugge	SINTEF-ER	*Restricted*
Effects of different harvesting systems on soil fungi: Methodology	Ari Hietala	NFLI	*Public*
Economic assessment of bioenergy	Per Kristian Rørstad, Birger Solberg	NMBU	*Public*
Value Chain Implementation Plan with Data Requirements	Francesco Cherubini, Gonzalo Del Alamo Serrano, Anders H. Strømman, Per Kristian Rørstad, Ryan Bright	NTNU	*Restricted*

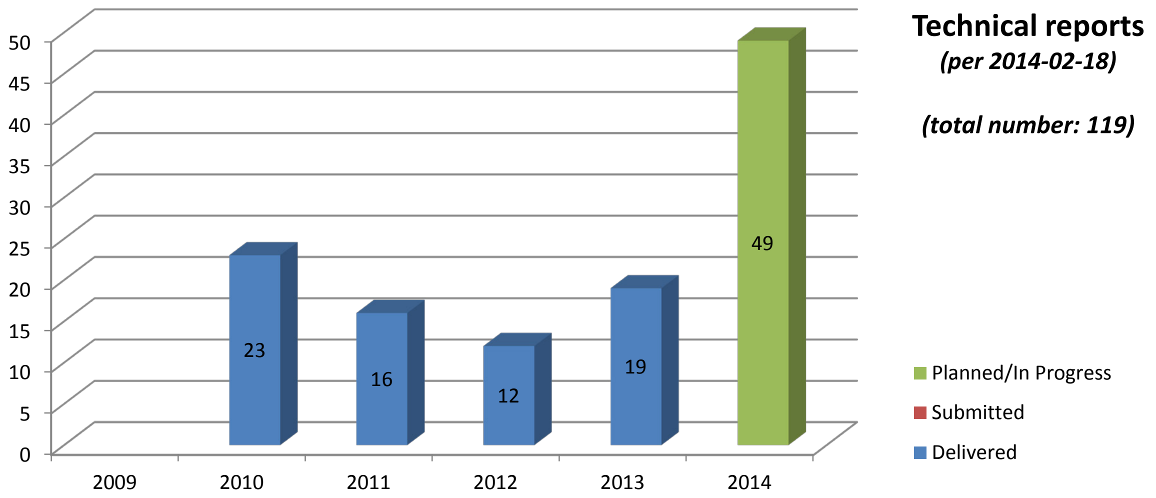

Figure 51: Status of technical reports published within CenBio.

Media contributions

We have listed most of the contributions from CenBio personnel during 2013, mostly in Norwegian media, in Table 24.

Table 24: List of media contributions 2013.

Title	Author(s)	Lead partner(s)	Media
The "dream fuel" is already here!	Svein Tønseth, Alexis Sevault	SINTEF-ER	*YEAR Newsletter*
Gamle vedovner ikke god nok	Morten Seljeskog	SINTEF-ER	*Dagens Næringsliv*
Vil ha bedre merket ved	Dalen L. S.	NFLI	*forskning.no*
Nasjonal vedkveld	Morten Seljeskog, Simen Gjølsjø	SINTEF-ER, NFLI	*NRK2*
Topp biobrensel fra skogbunnen	Svein Tønseth, Øyvind Skreiberg	SINTEF-ER	*Gemini*
Pris for energigjenvinning av forurenset trevirke			*forskning.no*
Får pris for å snu farlig til trygt	Peder Qvale		*Teknisk ukeblad*
Fra eksplosjon til pris	Ragnhild Fjellstad		*www.glomdalen.no*
Solør Bioenergi bruker farlig treavfall som råstoff - vant Bioenergy Innovation Award	Ruth Lothe		*NMBU (website)*
Solør Bioenergi er vinneren av "Bioenergy Innovation Award 2013"	Tekniske Nyheter		*TekniskeNyheter.no*
Award for energy recovery from contaminated wood materials	SFFE News		*SFFE News*
A City That Turns Garbage Into Energy Copes With a Shortage	John Tagliabue	EGE Oslo	*New York Times (both print and online)*
Alle åtte FME-er får fortsette	Claude R. Olsen	SINTEF-ER	*www.forskningsradet.no*
CenBio - Forskningssenter for miljøvennlig energi får tre nye år	Arne Bardalen	NFLI	*www.skogoglandskap.no*
UMB-forskere vant gjev pris	Kristine Løwe		*NMBU (website)*

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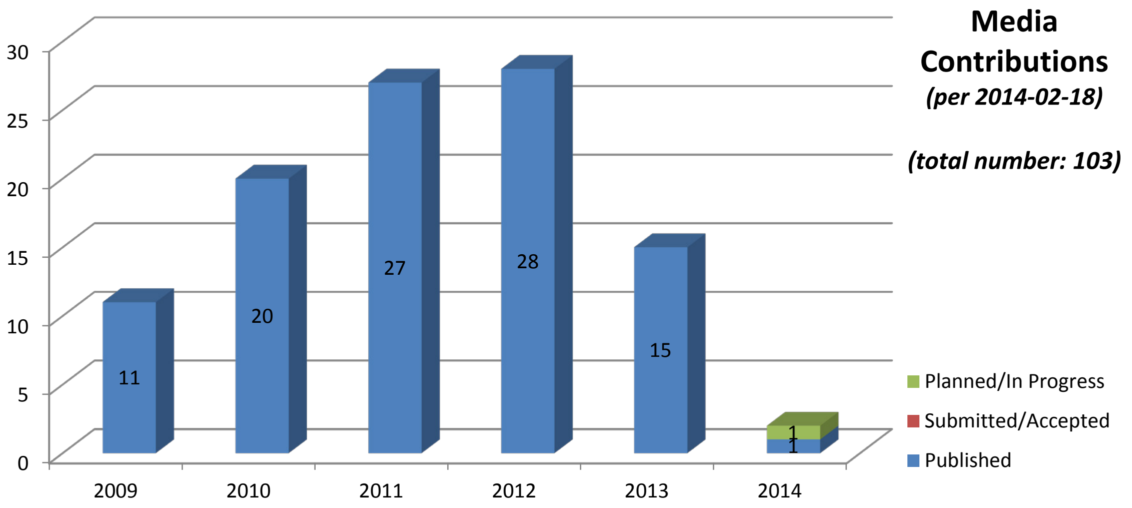

Figure 52: Status of media contributions published within CenBio.

D. Deliverables List

AWP2013 included a total of ***94*** deliverables. Of these, ***93*** were planned to be finalized in 2013. ***10*** deliverables were delayed from 2012 and transferred in February 2013 to the operative Deliverables list for 2013. Hence a total of 103 deliverables were scheduled to be finalized in 2013.

During 2013, ***34*** new deliverables were added to the 2013 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 25 below is therefore ***138***, with 137 deliverables due in 2013.

During the year, 10 deliverables were cancelled and 40 deliverables have not been finalized for various reasons. The delayed deliverables have been transferred to the 2014 Deliverables list. Almost all delays and cancellations can be explained by the following causes:

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

In total, ***87*** deliverables were finalized in 2013 (94% completion compared to AWP13).

In Table 25, the deliverables present in the operative Deliverables list for 2013 are shown. Most of the finalized deliverables can be accessed via the provided link (to the CenBio eRoom). The type of deliverables is indicated:

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

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Table 25: List of Deliverables 2013. The first column contains the links to the finalized deliverables in the Cenbio eRoom (access restricted to CenBio members).

**: In column "New", "n" stands for new deliverables, while "x" stands for those deliverables from 2012.*

Del. No	Deliverable title	Lead partner	Dated	Type	New*
D0.1.1_6	*Annual Work Plan 2014*	SINTEF-ER	*2013.12.31*	MR	
D0.1.2_51	*Progress report 1 2013*	SINTEF-ER	*2013.06.03*	MR	
D0.1.2_52	*Progress report 2 2013*	SINTEF-ER	*2013.12.01*	MR	
D0.1.3_5	*Accounts Report 2013*	SINTEF-ER	*2014.01.31*	MR	
D0.1.4_4	*Annual Report 2012*	SINTEF-ER	*2013.04.03*	MR	
D1.1.12	*Biomass expansion factors*	NFLI	*Delayed*	JP	
D1.1.16	*Biomass equations for birch (pop science article)*	NFLI	*Delayed*	O	
D1.1.17	*Adjacency constraints, simulated annealing and biomass potential*	NMBU	*2013.08.01*	JP	
D1.1.18	*Biomass quantification and adjancency constraints - Case Oslo municipality*	NMBU	*Delayed*	JP	
D1.1.19	*Estimating Birch biomass with terrestrial laser scanning*	NFLI	*Delayed*	JP	
D1.1.20	*Biomass equations for birch*	NFLI	*Delayed*	JP	n
D1.2.4	*Good practice guidelines for biomass production studies*	NFLI	*Delayed*	TR/JP	x
D1.2.5_3	*Network involved in supplying woody biomass for energy*	NFLI	*Delayed*	JP	x
D1.2.6	*Road Transport / Transport economic gains in new combi-truck concepts in an applied setting in Norway*	NFLI	*Delayed*	TR	
D1.2.11	*Economic sustainability of biomass feedstock supply (IEA joint paper)*	NFLI	*2013.01.31*	TR	
D1.2.12	*Supply chain cost analysis of ten alternative chains for high quality wood chip production*	NFLI	*2013.01.31*	TR	
D1.2.13	*Simple decision support tool for strategic evaluation of supply chain alternatives*	NFLI	*Delayed*	TR	
D1.2.14	*Joint supply chain evaluation*	NFLI	*Delayed*	TR/JP	
D1.2.15	*Input to SP6 Value Chains*	NFLI	*Delayed*	O	
D1.2.16	*Deriving cooperative biomass resource transport supply strategies in meeting co-firing energy regulations: A case for peat and wood fibre in Ireland*	NFLI	*2013.09.14*	JP	n
D1.2.17	*Recovery of logging residues from cable yarding*	NFLI	*Delayed*	TR	n
D1.2.18	*Performance of small scale straw-to-heat supply chains in Norway*	NFLI	*2013.11.21*	JP	n
D1.3.3	*Data about selected waste fractions characteristics*	SINTEF-ER	*2013.12.20*	O	
D1.3.5	*The Performance of a Residential Pellets Combustor Operating on Torrefied and Raw Spruce and Spruce Derived Residues*	SINTEF-ER	*2013.04.02*	JP	
D1.3.7	*Wood chip quality database*	NFLI	*2013.09.23*	TR	
D1.3.8	*Stem wood heating value and ash content of Norway spruce (Picea abies)*	NFLI/ SINTEF-ER	*Cancelled*	JP	
D1.3.9	*Branch wood heating value and ash content of Norway spruce (Picea abies)*	NFLI/ SINTEF-ER	*Cancelled*	JP	

D1.3.10	*Slagging properties of Northland forest trees*	NFLI/ SINTEF-ER	*Delayed*	JP	
D1.3.11	*Measuring of moisture content in wood chips with near infrared spectroscopy*	NLFI	*Delayed*	JP	
D1.3.12	*Experiments on ash properties of trees grown in steep terrain*	SINTEF-ER	*Delayed*	JP	
D1.3.13	*Value chain analyses; participation for the development of the work methodology*	NFLI/ SINTEF-ER	*Delayed*	O	
D1.3.14	*Inherent properties of Norway spruce biomass in some geographical locations in South Norway*	NFLI/ SINTEF-ER	*2014.02.14*	TR	n
D1.3.15	*Heating values and ash content in branches and stems*	NFLI/ SINTEF-ER	*Delayed*	TR	n
D1.3.16	*Chemical Composition of Norway spruce (picea abies) tree biomamm analyzes by STA*	NFLI/ SINTEF-ER	*2013.11.01*	JP	n
D1.3.17	*Simultaneous thermal analysis of ash samples from Norway spruce Biomass*	NFLI/ SINTEF-ER	*Cancelled*	JP	n
D1.4.2	*Efficiency of combined waste resources as N and P fertiliser to spring cereals*	Bioforsk	*2012.12.17*	TR	x
D1.4.4	*Combining waste resources as compound fertiliser to spring cereals*	Bioforsk/ NMBU	*2013.11.26*	JP	
D1.4.5	*Leaching of plant nutrients using waste based organic NPK fertilizers compared to mineral NPK fertilizers Efficiency of bottom wood ash as K fertiliser to spring cereals and ryegrass*	Bioforsk/ NMBU	*Delayed*	JP	
D1.4.7	*Wood ash in Portland cement clinker*	SINTEF-MC	*2011.12.19*	TR	x
D1.4.9	*P availability in solid biogas residues*	Bioforsk	*2013.03.05*	TR	
D1.4.10	*Evaluation of chemical extractions methods for determination of plant available phosphorus in ashes and other P rich waste materials*	Bioforsk/ NMBU	*Delayed*	TR	
D1.4.11	*Effects on different firing materials on combustion processes and ash quality*	Bioforsk/ SINTEF-MC	*Cancelled*	TR	
D1.4.12	*Wood ash as raw material for Portland cement*	SINTEF-MC	*2014.01.15*	PR	
D1.4.13	*Phosphorus case Norway: Focus on organic P-rich waste - First results of a P flow analysis - Opportunities for recycling of P-rich waste*	Bioforsk	*2013.03.05*	PR	n
D2.1.8	*NOx emission reduction by staged combustion - Modelling study*	SINTEF-ER	*2013.05.24*	JP	
D2.1.10_5	*IEA Task 32 activity report 2013*	SINTEF-ER	*2013.12.16*	O	
D2.1.11_5	*Bioenergy laboratory development 2013*	SINTEF-ER	*2013.12.16*	TR	
D2.1.12_1	*Testing of Zeolite and Kaolin for Preventing Ash Sintering and Fouling during Biomass Combustion*	SINTEF-ER	*2013.09.29*	PR	n
D2.1.12_2	*Testing of Zeolite and Kaolin for Preventing Ash Sintering and Fouling during Biomass Combustion*	SINTEF-ER	*2013.09.29*	CP	n
D2.1.12_3	*Additives and fuel mixes for reduced corrosion and fouling - Experimental study - phase 2*	SINTEF-ER	*2013.12.28*	JP	
D2.1.14	*Candidates for full-scale additives tests*	SINTEF-ER	*Cancelled*	O	
D2.1.15	*Numerical simulation of turbulent flames using the Eddy Dissipation Concept with detailed chemistry*	NTNU	*2013.05.14*	CP	n

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D2.1.16	*Influence of drag force correlations on periodic fluidization behavior in Eulerian-Lagrangian simulation of a bubbling fluidized bed*	NTNU	*2013.03.15*	JP	n
D2.1.17	*Eulerian-Lagrangian simulation of a bubbling fluidized bed reactor: Assessment of drag force correlations*	NTNU	*2012.09.14*	JP	n
D2.1.18	*Numerical investigation of particles turbulent dispersion in channel flow*	NTNU	*2012.09.12*	JP	n
D2.1.19	*Large-Eddy Simulation of the Flow Over a Circular Cylinder at Reynolds Number 2 × 10^4*	NTNU	*2013.09.01*	JP	n
D2.1.20	*Eulerian-Lagrangian Simulation of Wood Gasification in a High-Temperature Entrained Flow Reactor*	NTNU	*2013.06.25*	CP	n
D2.1.21	*Eulerian-Lagrangian simulation of biomass gasification in a high-temperature entrained flow reactor: effects of biomass type and particle size*	NTNU	*2013.12.05*	CP	n
D2.2.11_5	*IEA Task 33 activity report 2013*	SINTEF-ER	*2/year*	O	
D2.2.12	*Literature review on syngas oxidation mechanisms*	Energos	*Cancelled*	TR	
D2.2.13	*Reduced syngas oxidation mechanisms*	Energos	*Cancelled*	TR	
D2.2.14	*A simplified approach for municipal solid waste gasification modelling*	SINTEF-ER	*2013.05.29*	CP	
D2.2.15	*Gasification modelling – Phase 1*	NTNU	*Cancelled*	JP	
D2.2.16	*Ash & trace metals chemistry: thermodynamic equilibrium database (working title: S-Cl-Na-K chemistry during MSW gasification: a thermodynamic study)*	SINTEF-ER	*Delayed*	JP	
D2.2.17	*Overview of gasification activities in GasBio*	SINTEF-ER	*2013.12.19*	O	
D2.3.X	*High temperature charcoal carbonization (working title)*	SINTEF-ER	*Delayed*	JP/CP	x
D2.3.7_2	*EERA Bioenergy: 2013 activities*	SINTEF-ER	*2013.12.16*	O	
D2.3.8	*Exchange/seminar with Hawaii University*	SINTEF-ER	*2013.02.21*	O	
D2.3.9	*Prosjektforslag "BioCarb+": Enabling the biocarbon value chain for energy*	SINTEF-ER	*2013.02.18*	PR	
D2.3.10	*BioCarb+ project description*	SINTEF-ER	*2013.02.18*	O	
D2.3.11	*The smart biofuels of the future*	SINTEF-ER	*2013.02.28*	JP	n
D2.3.12	*Attainment of High Fixed-Carbon Yields from Biomass*	SINTEF-ER	*2013.02.14*	PR	n
D2.3.13_1	*Experimental Study of a Single Particle Reactor at Combustion and Pyrolysis Conditions*	SINTEF-ER	*2013.09.29*	PR	n
D2.3.13_2	*Experimental Study of a Single Particle Reactor at Combustion and Pyrolysis Conditions*	SINTEF-ER	*2013.09.29*	CP	n
D2.4.6_5	*Minutes from IEA Task 37 meetings 2013*	Bioforsk	*Cont.*	O	
D2.4.11	*Effect of pretreatment on anaerobic digestion*	Bioforsk	*Delayed*	JP	x
D2.4.12	*Demonstration of anaerobic digestion of cow manure in 6 m^3 pilot reactor*	Bioforsk	*Delayed*	TR	x
D2.4.13	*Fish waste raw material for anaerobic digestion*	Bioforsk/NMBU	*Delayed*	TR	x
D2.4.15	*Peer reviewed scientific publication on pretreatment of grass.*	NMBU	*Delayed*	JP	

D2.4.19	*Peer reviewed journal paper on the microbial composition of anaerobic digestion cultures*	Bioforsk	*Delayed*	JP	
D2.5.2	*Thermal decomposition kinetics of woods with emphasis on torrefaction*	SINTEF-ER	*2013.09.18*	JP	n
D2.5.3	*Comparative assessment of wet torrefaction*	SINTEF-ER	*2013.10.08*	JP	n
D2.5.4	*STable OPerating conditions for biomass combustion plants*	SINTEF-ER	*2013.12.17*	CB	n
D3.1.4_5	*Reports from standardization meetings*	SINTEF-ER	*2014.01.09*	O	
D3.1.7	*Methods and operational principles for further decreased particle emission levels from wood stoves*	SINTEF-ER	*2014.02.13*	PR	
D3.2.6_5	*IEA Task 36 activity report 2013, including a report about biogenic C*	SINTEF-ER	*2013.12.16*	O/PR	
D3.2.7_5	*PREWIN activity report 2013*	SINTEF-ER	*2013.12.16*	O	
D3.2.11	*New waste fractions properties*	SINTEF-ER	*Cancelled*	PR	
D3.2.12	*Bottom ash from WtE*	SINTEF-ER	*2014.01.02*	PR	
D3.3.4	*Optimisation to achieve minimum corrosion rate and maximum NOx and CO reduction*	VRD	*2014.01.23*	TR	
D3.3.6	*Short term measurements 1 and 2*	VRD	*2013.05.14*	TR	
D3.3.7	*Long term test*	VRD	*Delayed*	TR	
D3.4.6	*Measurement campaign planning (Akershus Energi)*	SINTEF-ER	*Delayed*	TR	
D3.4.7	*NOx formation - Initial CFD study*	SINTEF-ER	*2013.09.11*	TR	
D3.4.8	*Measurement campaign (Akershus Energi)*	SINTEF-ER	*Delayed*	TR	
D3.4.9	*NOx formation – CFD study*	SINTEF-ER	*Delayed*	JP	
D4.1.11	*Premises for biodiversity indicator design in LCA*	NTNU	*Delayed*	JP	
D4.1.28	*Bioenergy from forestry and changes in atmospheric CO_2: Reconciling single stand and landscape level approaches*	NTNU	*2013.07.15*	JP	
D4.1.34	*Empirical models of monthly and annual albedo in managed boreal forests of interior Norway*	NTNU	*2013.05.06*	JP	
D4.1.35	*Consistent quantification of climate impacts due to biogenic carbon storage across a range of bio-product systems*	NTNU	*2013.05.13*	JP	
D4.1.36	*Climate change implications of shifting forest management strategy in a boreal forest ecosystem of Norway*	NTNU	*2013.10.09*	JP	
D4.1.37	*Bioenergy vs. natural gas for production of district heat in district heat in Norway: Climate implications*	NTNU	*2013.12.13*	JP	n
D4.1.38	*Global climate impacts of forest bioenergy: what, when and how to measure?*	NTNU	*2013.05.28*	JP	n
D4.1.39	*Biogenic CO_2 fluxes from bioenergy and climate—A response*	NTNU	*2013.02.17*	JP	n
D4.1.40	*Land use impacts on biodiversity from kiwifruit production in New Zealand assessed with global and national datasets*	NTNU	*2013.07.09*	JP	n
D4.2.6	*Effects of different harvesting systems on soil fungi: Methodology*	NFLI	*2013.04.20*	TR	x
D4.2.11	*Whole-tree thinnings in stands of Scots Pine (Pinus sylvestris) and Norway spruce (Picea abies): Short- and long-term growth results*	NFLI	*2013.02.28*	JP	

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D4.2.12_1	*Modelling the ecological consequences of whole tree harvest for bioenergy production*	NFLI	*2013.04.16*	PR	
D4.2.12_2	*Modelling the ecological consequences of whole tree thinning for bioenergy production*	NFLI	*2013.05.24*	PR	n
D4.2.12_3	*Modelling the consequences of slash removal after thinning in boreal forest plots using Generalized Additive Models (GAMs)*	NFLI	*2013.09.19*	JP	
D4.2.13	*Journal paper on harvesting effects on soil organic carbon*	NFLI	*Delayed*	JP	
D4.2.14	*Approaches to soil sustainability in guidelines for forest biomass harvesting and production in forest and plantations*	NFLI	*2013.04.01*	CP	
D4.2.15	*Presentation "Environmental impacts of harvesting biomass from the Nordic forests"*	NFLI	*2013.05.22*	PR	n
D4.2.16	*Presentation "Environmental Services Provided by Forests - an Overview"*	NFLI	*2013.06.11*	PR	n
D4.3.8	*Costs and production inputs of bioenergy production*	NMBU	*Delayed*	TR	x
D4.3.11	*Conceptual report on what is meant by sustainable bioenergy production, and discussion of corresponding criteria and indicators*	NMBU	*Delayed*	TR	
D4.3.16	*Estimation of the carbon leakage effects of increased harvest in Norway*	NMBU	*Delayed*	JP	
D4.3.21	*Economic assessment of bioenergy*	NMBU	*2013.12.18*	TR	
D4.3.22	*A review of recent developments and applications of partial equilibrium models of the forest sector*	NMBU	*2013.06.24*	JP	
D4.3.23	*Market impacts of increased competition between the forest biofuels and fossil fuels*	NMBU	*Cancelled*	JP	
D4.3.24	*Wood biomass use for energy in Europe under different assumptions of coal, gas and CO_2 emission prices and market conditions*	NMBU	*2013.10.15*	JP	
D4.3.25	*Future prices of biomass for energy and competition over fibre*	NMBU	*Delayed*	PR	-
D5.1.8_5	*PhD workshop 2013, CenBio graduate school*	NTNU	*2013.04.30*	O	
D5.1.11	*Development and delivery of Post graduate course in Life cycle assessment of bioenergy systems.*	NTNU	*Delayed*	O	
D5.2.18	*4 industry workshops*	SINTEF-ER	*Delayed*	O	
D5.2.19	*3 industry cases*	NMBU	*Delayed*	O	
D5.2.20	*Scientific publishing: 20 scientific papers submitted, 10 conferences papers*	NMBU	*2013.12.31*	JP/CP	
D5.2.21	*CenBio website*	NMBU + SINTEF-ER	*cont.*	MR	
D5.2.22	*CenBio conference April 2013*	SINTEF-ER	*2013.04.10*	O	
D5.2.23	*External conferences and presentations: 10 international conferences, seminars, workshops; 10 presentations*	SINTEF-ER	*2013.12.31*	PR	
D5.2.24	*Popular publishing: 20 popular articles and press news*	NMBU + all WPs	*2013.12.31*	PT	
D5.2.25	*Best of CenBio*	SINTEF-ER	*2013.03.01*	O	n
D5.2.26	*CenBio Strategic Day 2013*	SINTEF-ER	*2013.10.31*	O	n
D5.3.8_3	*Status of CenBio Innovations, 3rd version*	SINTEF-ER	*2013.12.23*	O	
D5.3.10_3	*Extending the CenBio activities - Status*	SINTEF-ER	*2014.02.12*	O	

D5.3.11_3	*Award the 3rd Bioenergy Innovation Award*	SINTEF-ER	*2013.04.30*	O
D5.3.12	*Third Innovation workshop*	SINTEF-ER	*2013.06.28*	O
D6.1.01	*Value Chain Implementation Plan with Data Requirements*	NTNU	*2013.06.27*	TR

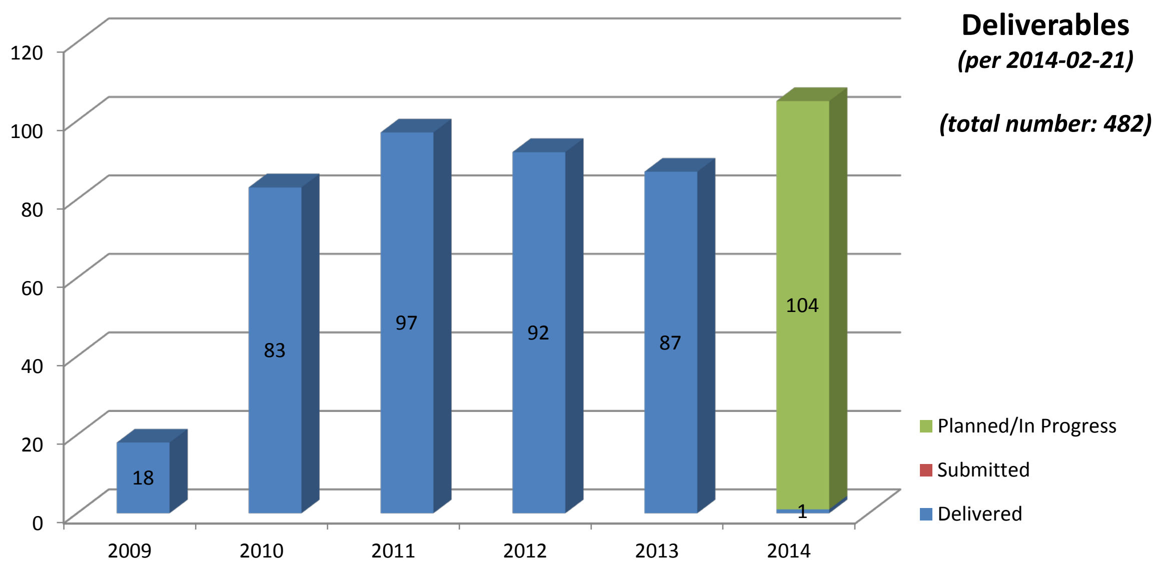

Figure 53: Status of deliverables achieved within CenBio.

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E. List of Partners – short names

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

Table 26: Short names of partners.

No	Short name	Entity legal name
01	NMBU	Norges miljø- og biovitenskapelige universitet **(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
11	NTE	NTE Holding AS
12	HAFSLUND	Hafslund ASA
13	STATKRAFT	Statkraft Varme AS
16	PROTEIN	Norsk Protein AS
19	EGE	Oslo Kommune Energigjenvinningsetaten
21	VHN	Vattenfall Distribution and Sales, business unit Heat
22	ENERGOS	Energos AS
23	CAMBI	Cambi AS
24	JØTUL	Jøtul AS
26	GKAS	Granit Kleber AS

F. References

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

Annual Work Plan 2014
Annual Report 2011
Annual Report 2012

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

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