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CenBio - the Bioenergy Innovation Centre - is one of eight 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 industrial partners and the participating research institutions.

Universitetet for miljø- og biovitenskap (Norwegian University of Life Sciences) is Host institution, and SINTEF Energi AS (SINTEF Energy Research) is Coordinating institution.

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SUMMARY

Sustainable energy contribution

Twenty-five years ago, the Brundtland Report gave birth to the notion of "sustainability". At CenBio, this concept is a guiding star for each and every one of us. The Brundtland Commission emphasised that our current needs must be fulfilled without infringing the rights of the coming generations to be able to meet their own needs. Others have added that sustainability is also about ensuring that economic and social development and environment protection join forces and even mutually reinforce one another.

In the Norwegian context, we have extended the sustainability concept to include energy use when it is climate- and environmentally friendly, efficient and profitable. As CenBio reaches its halfway mark, it is with great pleasure and pride that we can claim that it has generated knowledge and technologies that have enabled the bioenergy sector to improve on all these counts.

Until now, bioenergy in Norway has mainly been about wood- and woodchip-firing. These will continue to be important in the future, and CenBio is striving to improve and refine these branches of the bioenergy sector. In addition we aim to establish the foundations of new value chains within the bioenergy sector in Norway – for example, biogas production and CHP (combined heat and power).

As this annual report demonstrates, many CenBio activities focus on the development of technologies and knowledge which will improve bioenergy generation, whether forest harvesting, logistics, pre-treatment of biomass or energy conversion. Put in a different way, we are very much into innovation – broadly speaking. We hope that CenBio will pave the way for both new commercial products and novel processes in the bioenergy market. In fact, we have already produced several innovations in the form of experimental set-ups and analytical (measuring) methods, which we hope will provide a strong foundation for further developments in the future.

The fact that we have been able to achieve so much already is undoubtedly thanks to the strong national team built along the Trondheim-Ås axis. Our cooperation has given us a unique opportunity to link scientific expertise in forest and agricultural bio-resources with scientific and technological competence in energy conversion.

CenBio is now entering a new phase, in which great emphasis will be put on increased interaction with other research groups in the Nordic countries. Sharing expertise with our neighbours will help both them and Norway to develop our vast bioenergy resources to our mutual benefit.

Lars Sørum
Centre Coordinator
SINTEF Energi AS,
Coordinating Institution
(photo: Gry Karin Stimo)

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

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VISION AND GOAL

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

CenBio Vision 2020

	TWh - Today:				TWh - 2020:			
	Input	Efficiency	Output		Input	Efficiency	Output	
Wood / pellet stoves	7	0,6	4,2	→	12	0,85	10,2	Wood / pellet stoves
District heat	2,7	0,85	2,3		6	0,9	5,4	District heat
Wood industry	4,4	0,85	3,7		5	0,9	4,5	Wood industry
CHP - heat	~ 0	0,6	~ 0		4	0,65	2,6	CHP - heat
CHP - power		0,2				0,3	1,2	CHP - power
Power	~ 0	0,4	~ 0		1	0,5	0,5	Power
Biogas	~ 0	0,5	~ 0	Documented overall sustainability	2	0,7	1,4	Biogas
SUM	**14,1**		**10,2**		**30**		**25,8**	**SUM**

Figure 1: CenBio Vision 2020

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

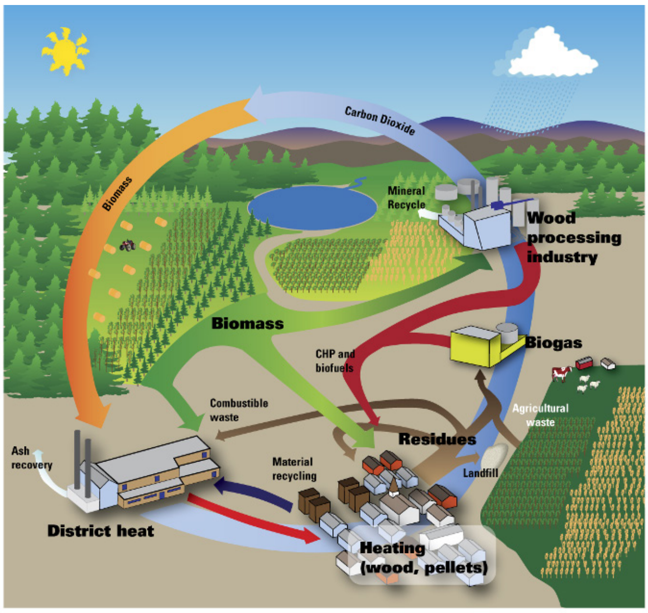

Figure 2: CenBio scope

As a result of our activities, consumers will get access to different forms of environment-friendly energy, and society will be supplied with more renewable and CO_2-neutral energy. A further benefit will be the establishment of a Norwegian bioenergy industry and therewith a substantial number of new jobs, especially in rural districts.

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RESEARCH PLAN

CenBio description

The overall objectives and principal work plan are explained in the centre description prepared during the application phase. The original description is referred to in the R&D Agreement between RCN and the host institution UMB. 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 course of the research may have to be changed due to external conditions.

Annual Work Plan (AWP)

AWP2011

The planning of research activities for 2011 started in October 2010 when the Centre Management Team (CMT) met physically in Trondheim. All partners were invited to give input to the plan through the Sub Project leaders. A draft AWP2011 was presented for EB approval at its meeting in Oslo 26 November 2010. Minor comments from EB were implemented and the final AWP was sent to RCN on 31 December 2010.

AWP2012

The planning of research activities for 2012 started in September 2011. The Sub Project leaders met with the core management team for a two-day workshop, which also included discussions about innovation and bioenergy value chains. All partners were invited to propose input to the plan, and to comment a draft version in October. The draft AWP2012 was presented for EB approval at its meeting in Trondheim 23 November 2011. Minor comments from EB were implemented and the final AWP was sent to RCN on 30 December 2011.

Joint laboratories

CenBio conducts most of its experiments in four dedicated laboratories, partly funded by RCN (The Research Council of Norway).

Biochemical conversion lab Biogas lab Thermochemical conversion

Figure 3: Joint laboratories (photo: UMB and SINTEF)

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The laboratories are:

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

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ORGANISATION AND COORDINATION

Coordinating a research centre with 26 partners is a challenging task

My experience in coordinating large EU projects with up to 30 partners was crucial when the detailed rules and procedures needed for daily operation were established at the very start of the CenBio centre. Templates, procedures and other administrative tools such as timetables and contact lists are all essential; some of these are discussed in more detail in the following pages.

Some of the most important procedures, such as the Invoicing and Payment Plan, had to be approved by the Executive Board. In some cases we had to amend the initial rules and procedures on the basis of operational experience.

One of the most challenging tasks that we face is monitoring the overall progress to be reported to the Executive Board, the General Assembly and to the Research Council of Norway. We have established direct contact with specific personnel in the accounting departments of the partners, and three times a year they report on the current financial situation. Scientific progress is mainly monitored via status reports on each planned deliverable; this is done monthly during the Centre Management Team teleconferences.

The partners report individually to the Centre Manager, either directly or through the Sub Project/Work Package organisation. Financial reporting is mainly direct, while technical reporting goes through CenBio's thematic organisational structure. The Centre Manager ensures that all reporting is sent to the Research Council of Norway.

I can safely say that without our experience of coordinating large international research projects, the management of CenBio would not have gone as smoothly as it is today.

Einar Jordanger
Centre Manager
(photo: Gry Karin Stimo)

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Partners

Initially 26 partners were participating in CenBio. Universitetet for miljø- og biovitenskap (UMB) is host institution and SINTEF Energi AS is coordinating institution. The governance structure is further elaborated under Organisation and Coordination.

During 2011 one partner has withdrawn from the centre. BioNordic AS was declared bankrupt since the market for their products decreased substantially.

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

Research partners

There are seven Research partners in CenBio:

Universitetet for miljø- og biovitenskap (Host institution)
SINTEF Energi AS (Coordinating institution)
Norges teknisk-naturvitenskapelige universitet NTNU
Bioforsk
Norsk institutt for skog og landskap
Stiftelsen SINTEF
Vattenfall Research and Development AB (Sweden)

Industrial partners

The 16 Industry partners at the end of 2011 are shown below:

Akershus Energi AS
Norges Skogeierforbund
Agder Energi AS
NTE Holding AS
Hafslund ASA
Trondheim Energi Fjernvarme AS
Norske Skogindustrier ASA
Norsk Protein AS
Avfall Norge
Norges Bondelag
Oslo Kommune Energigjenvinningsetaten
Vattenfall AB, Heat Nordic (Sweden)
Energos AS
Cambi AS
Jøtul AS
Granit Kleber AS

A list of short names used for convenience is shown in Table 21.

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Governance structure

The governance structure as defined in the Consortium Agreement is shown in Figure 4.

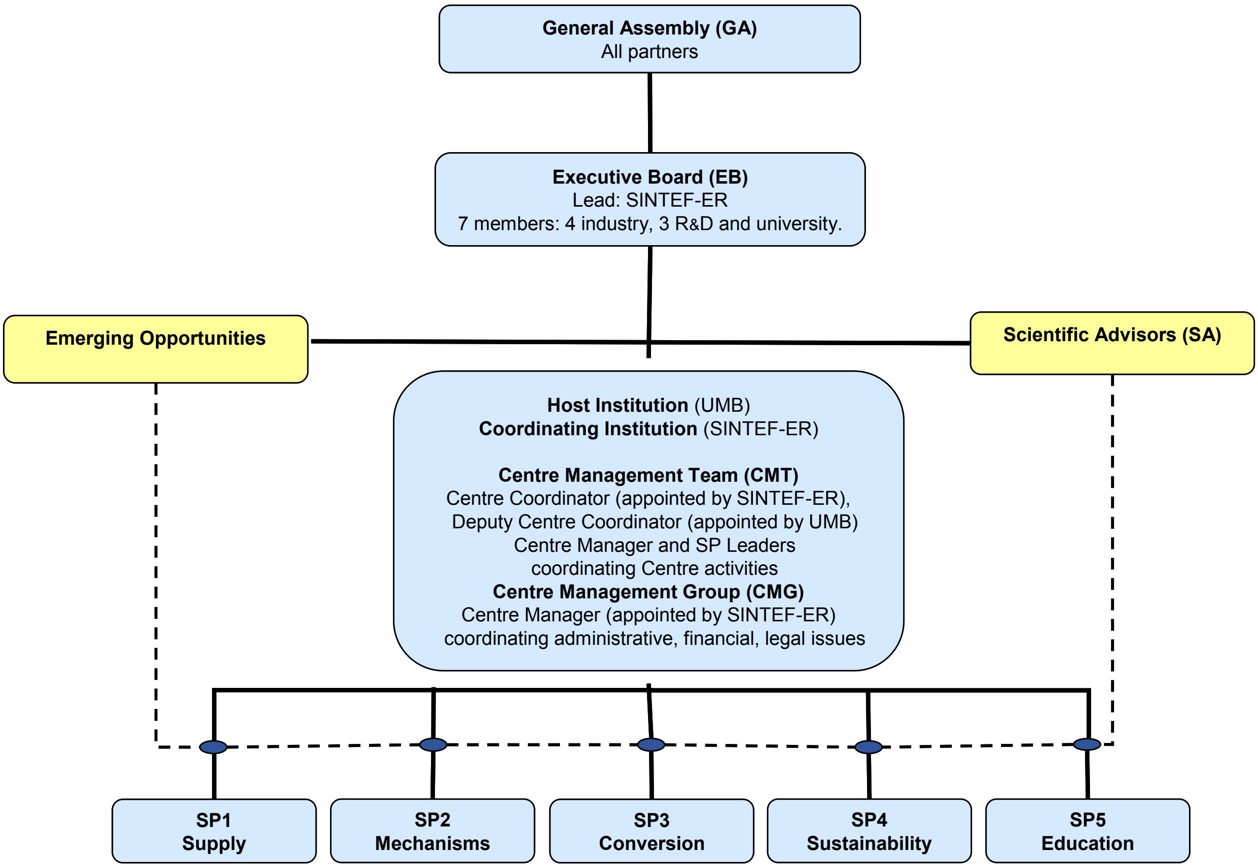

Figure 4: CenBio Governance Structure. SP stands for Sub Project.

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

The Executive Board (EB) consists of seven members, three representing Research partners and four from Industry partners. The Coordinating organisation appoints the chairperson.

Table 1: Executive Board members 2011

Position	Name	Affiliation
Chairperson	Mona J. Mølnvik/Petter Støa	02 SINTEF-ER
EB Member (Research)	Ragnhild Solheim	01 UMB
EB member (Research)	Olav Bolland	03 NTNU
EB member (Industry)	Morten Fossum	13 STATKRAFT
EB member (Industry)	Rune Dirdal	17 AVFALLN
EB member (Industry)	Hans Olav Midtbust	22 ENERGOS
EB member (Industry)	Bjørn Håvard Evjen	09 SKOGEIER

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

Table 2: Centre Management Team

Position	Name	Affiliation
Centre Coordinator	Lars Sørum	02 SINTEF-ER
Deputy Centre Coordinator	Odd Jarle Skjelhaugen	01 UMB
Centre Manager	Einar Jordanger Michaël Becidan	02 SINTEF-ER 02 SINTEF-ER
SP1 leader	Simen Gjølsjø	05 NFLI
SP2 leader	Michael Becidan	02 SINTEF-ER
SP3 leader	Øyvind Skreiberg	02 SINTEF-ER
SP4 leader	Birger Solberg	01 UMB
SP5 leader	Anders H. Strømman	03 NTNU

Scientific Advisors (SA) were established during 2010, one for each Sub-Project except 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 organised in five Sub Projects (SPs) which again are divided into three to four/five Work Packages (WPs). A separate WP is defined to separate the management activities from the technical work, under SP0. The WBS is shown in Table 4.

Table 4: Work Breakdown Structure

SP No	SP title WP No and title
SP0	**Centre Management and Coordination** WP0.0 Management
SP1	**Biomass Supply and Residue Utilisation** WP1.1 Feedstock supply WP1.2 Logistics WP1.3 Biomass and residue characteristics and uality WP1.4 Residue upgrading and use
SP2	**Conversion Mechanisms** WP2.1 Combustion WP2.2 Gasification WP2.3 Pyrolysis WP2.4 Anaerobic digestion WP2.5 KMB STOP: torrefaction

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SP No	SP title WP No and title
SP3	**Conversion Technologies and Emissions** WP3.1 Wood / pellet stoves WP3.2 District heat WP3.3 Heat and power WP3.4 Emissions
SP4	**Sustainability assessments** WP4.1 Life Cycle Assessment (LCA) WP4.2 Ecosystem management WP4.3 Cost assessment and market analysis
SP5	**Knowledge Transfer and Innovation** WP5.1 Bioenergy Graduate School WP5.2 Knowledge transfer and dissemination WP5.3 Innovation management

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. In some Work Packages partners both from Ås and Trondheim participate and in some instances there is cooperation between different WPs. Such cooperation should be documented in the annual plans.

The industrial partners also contribute with in-kind research, and in some cases researchers from the universities or research institutes perform research at their installations or plants. Cooperation between the various WPs and associated industrial partners are described in chapter 0.

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

Once a year the centre invites all partners to attend the CenBio Days. Up to now this event has been arranged in January in conjunction with the General Assembly where all partners are supposed to participate. Also international experts and CenBio Scientific Advisors (SA) are invited to present state-of-the-art in various countries.

In 2011 the CenBio Days took place in Trondheim 17-18 January. Presentations from selected researchers and invited representatives from industrial partners were given in plenary sessions. Special topics like innovation and education were discussed in workshop sessions with subsequent reporting in a plenary session. Three of four scientific advisors gave key notes about bioenergy research in Finland and in the US.

One example of cooperation between the research groups at Ås and Trondheim could be mentioned: SP1 includes the "forest side" through production and the "utilization side" since the properties determine the process performances and the "ash side" to investigate what can be done with the residues. Figure 5 shows the scope for SP1 which include research activities with related laboratory experiments both at Ås and Trondheim. Researchers have been visiting colleagues and worked together at both premises.

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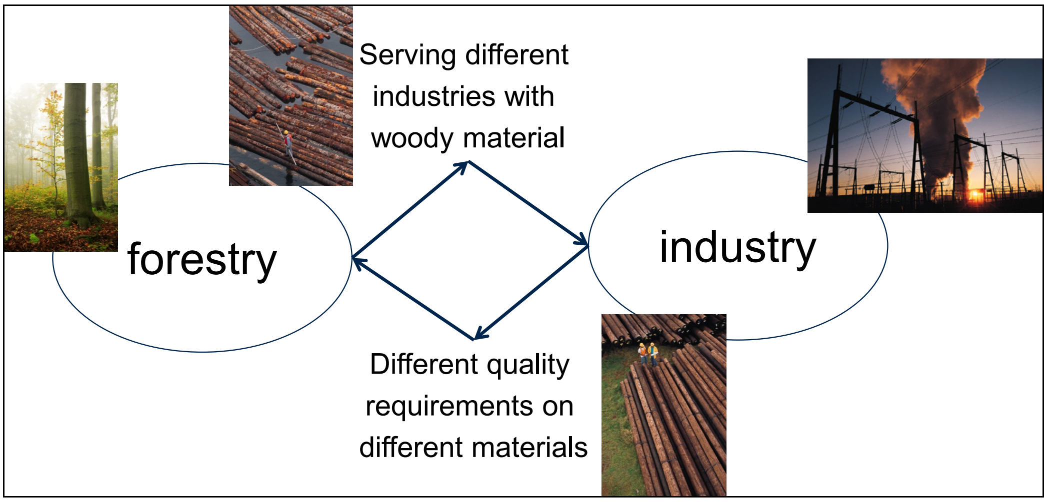

Figure 5: Scope for SP1 Biomass Supply and Residues Utilisation

The cooperation between research groups at Ås an in Trondheim has certainly given added value to the bioenergy research in Norway.

Management and Coordination

General

The overall coordination activities are organised within a separate work package, WP0.1 Management and Coordination. During 2011 the main activities have been to reporting costs and progress, arranging coordination meetings, and to coordinate the planning of future research activities. Management within each SP is the responsibility of respective SP- and WP leader.

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 2011 approximately 100 persons had access to the eRoom. The overall structure of the CenBio eRoom is shown in Figure 6.

The folder structure is shown to the left. Folder 050 Meetings and 02 EB meetings have been expanded to show three levels as an example. Also folder 100 SP1 Supply and WP1.1 Feedstock Supply have been expanded to show the common structure for all SPs and WPs.

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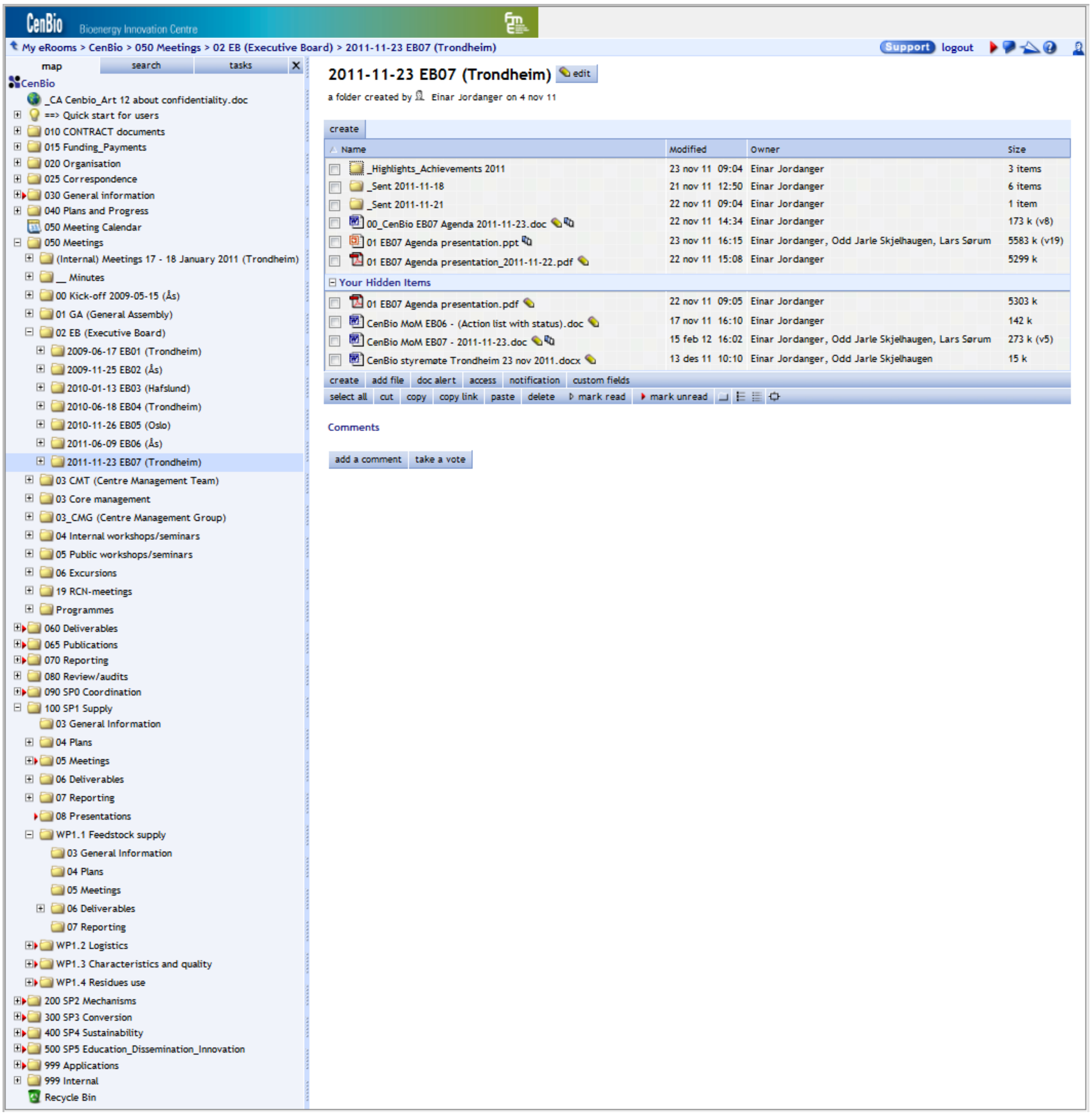

Figure 6: CenBio eRoom structure

Meetings

The Centre Management Team had eight meetings in 2011, and the Core Management Team met nine times. The Executive Board had two meetings, in June and in November, and the General Assembly met on 17 January in Trondheim. Most CMT meetings are arranged as teleconferences using eRoom for sharing documents and information.

Deliverables list and Publication database

In order to keep track of planned deliverables including journal papers for review an Excel workbook is established (in Folder 060 in the eRoom). All deliverables are listed with a unique number. When a new annual work plan is approved the associated list of deliverables is added to the workbook. Progress is updated regularly, and when the calendar year is ended possible

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unfinished deliverables are transferred to the next year. Hence finalised deliverables are documented in the remaining annual list, as shown in Table 20.

Following up progress of journal papers/scientific articles that are subject to peer-review requires a more detailed follow-up 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.

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RESEARCH ACTIVITIES

SP1 Biomass supply and residue utilization

Forest feedstock

This sub-project deals with forest feedstock supply, feedstock quality, logistics and economics. It also includes the recycling of wood ash from combustion and bio-residues from biogas production.

The regular measurements of the Norwegian National Forest Inventory reveal that near 98% of the biomass is located in areas defined as forest. In Cenbio we have also assessed the potential bioenergy production from "trees outside forest". Such areas are capable of adding a biomass equivalent to maximum 1.77 TWh bioenergy annually, where for example trees under power lines may provide about 0.21 TWh, road and railway shoulders about 0.66 TWh and urban areas about 0.26 TWh. Compared with Norway's 16 TWh total bioenergy consumption in 2011, these so-called marginal areas will have less impact on the total energy supply.

Using advanced modelling tools, we estimate the total cost of using branches and tops as bioenergy feedstock at 0.17 NOK/kWh, supplied as wood chips. This price is in the same range as for other raw materials for heat generation.

The quality of wood chips seriously affects the efficiency of heating plants and the composition of their emissions to air. Combining scientific expertise in biology and technology is essential if we are to provide the optimal combinations of chip quality and technology to achieve minimal pollution, high efficiency and sound economics.

Ash from bioenergy plants may contain significant concentrations of heavy metals. We obviously need to find acceptable ways to handle this problem. Since heavy metals are "natural", i.e., they are retrieved by trees growing in soils that contain heavy metals, the ash can be recycled in the areas where the biomass was harvested.

Simen Gjølsjø
Leader of Biomass supply and residue utilization
(photo: Lars Sandved Dalen)

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WP1.1 Feedstock supply

In 2007, the Norwegian government proposed to increase the annual use of bioenergy by 14 TWh by year 2020, which was an approximate doubling of the current production. Possible sources for more biomass for bioenergy from forest are primary forest production like roundwood and harvest residues and secondary products like forest industry residues and waste wood. A significant part of this increase needs to come from primary forest production where the following resource categories may be considered;

- Branches and tops from final felling
- Branches and tops from early thinning
- Roots and stumps from final felling
- Traditional fuel wood harvesting
- Trees outside forest

From Norwegian National Forest Inventory (NFI) sample data we have assessed the potential for energy production based on forest residues (branches and tops) from final felling. Cost-supply curves, based on spatially explicit information on environmental constraints and harvesting conditions (terrain properties and distance to road), have been developed. These curves show that the potential annual energy production from forest residues vary between 3-6 TWh depending on residue extraction costs level. A higher energy production than 6 TWh from harvest residues is considered unrealistic without an increase in the general timber harvesting level in Norway. The potential energy production based on residues from early thinning in Norway is considered marginal due to high extraction costs. The theoretical amount of biomass, based on roots and stumps that can be harvested after final felling, is at the same level as for forest residues. However, due to environmental concerns, a lack of appropriate harvesting methods and equipment, and extraction costs, the energy supply also from this source can only be marginal. The statistics on use of traditional fuel wood in Norway is insufficient. From a resource point of view there is probably a potential to increase this production. To quantify a potential increase, however, is difficult due to lack of statistics and fluctuating market conditions.

High expectations to "trees outside forest" as a source for energy production have frequently been expressed publicly in Norway. A study based partly on NFI data and field work covering entire Norway revealed that there certainly is a potential, although limited. The theoretical annual potential from such areas, based on different assumed rotation ages for the different area types, is estimated to 1.77 TWh (see Table). Due to environmental constraints and inaccessibility (see picture) the production will be lower. In addition, since extraction of these resources need to be done over large scattered areas, the costs are likely to be very high for substantial parts. Realistically, the annual energy production from these areas will not exceed 1.0 TWh.

The target of an increased production of 14 TWh by 2020 can therefore not be reached without either increasing the general timber harvesting level in Norway quite substantially or by replacing biomass for energy from stem wood on the expense of pulp wood production.

Potential annual energy production based on "trees outside forest" in Norway is shown in Table 5.

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Table 5: Potential annual energy production based on "trees outside forest" in Norway

Area type	Biomass (mill. ton d.w.)	Biomass density (ton d.w./ha)	Annual potential energy production (TWh)
Power lines	0.390	6.13	0.21
Borders along roads, etc	1.254	6.33	0.66
Urban areas	2.453	6.31	0.26
Agricultural areas	1.397	1.43	0.15
Pasture	3.027	15.46	0.32
Cottage areas	1.568	33.26	0.17
Total	10.089	5.41	1.77

Figure 7: Extraction of resources based on "trees outside forest" is likely to be high. Red cross: centre point of sample plots from the Norwegian National Forest Inventory. (photo: Norge i bilder, Norsk institutt for skog og landskap)

WP1.2 Logistics

This WP deals with the harvesting and supply of biomass from standing tree to plant gate. The purpose is to evaluate and document good solutions through an analysis of their underlying drivers and benefits. Apart from those already operating in Norway, the WP also closely monitors developments in Scandinavia and internationally, in an effort to ensure that best practices are introduced into Norwegian supply chains.

International activities and cooperation

Conferences and Symposia

4th World Forest Engineering Conference

This international conference is held every 4 years and gathers all significant research environments working with forest technology, forest engineering and forest operations. Due to the high level of international activity in the field, there is a strong focus on bioenergy.

Talbot, B., Søvde, N.E. & Suadicani, K. 2011. Using network analysis in configuring appropriate biomass supply systems. In: Ackerman, P., Ham, H. & Gleasure, E (eds.) Proceedings of the 4th World Forest

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Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change , White River, South Africa, April 5-7, 2011. ISBN: 978-0-7972-1284-8.

Hohle, A. 2011. Energy consumption and emissions in selected biomass supply chains. In: Ackerman, P., Ham, H. & Gleasure, E (eds.) Proceedings of the 4th World Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change , White River, South Africa, April 5-7, 2011. ISBN: 978-0-7972-1284-8.

COST FP0902: Development and harmonisation of new operational research and assessment procedures for sustainable forest biomass supply

NFLI is well represented in the above group, which held its annual meeting together with the International Symposium on Forestry Mechanisation (FORMEC) in Graz, Austria. Three presentations were held by participants of WP1.2.

Hohle, A. 2011. Energy consumption by energy wood supply. In: Kühmaier, M. (ed) Proceedings of the 44th International Symposium on Forestry Mechanisation (FORMEC), Graz, Austria. 9th-13th October 2011.

Belbo, H. 2011. A simulation approach to determine the potential efficiency in multi-tree felling and processing. In: Kühmaier, M. (ed) Proceedings of the 44th International Symposium on Forestry Mechanisation (FORMEC), Graz, Austria. 9th-13th October 2011.

Nordhagen, E. 2011. The drying of wood chips with surplus heat from two hydroelectric plants in Norway. In: Kühmaier, M. (ed) Proceedings of the 44th International Symposium on Forestry Mechanisation (FORMEC), Graz, Austria. 9th-13th October 2011.

Networks and Workshops

International Energy Agency (IEA) Bioenergy Task 43: Biomass Feedstocks for Energy Markets
WP1.2 participates in this important IEA group that considers biomass resources and the delivery of these to energy markets. There was however, no participation in the annual meeting held in Campinas, Brazil (Sept. 19-21). NFLI is involved in drafting one of the main Task deliveries for the present triennium: *Economic sustainability of biomass supply*. The final report is due medio 2012.

SNS – Operations Systems Centre of Advanced Research (OSCAR)
This Nordic-Baltic network is supported by the Nordic Council of Ministers (SNS) and promotes cooperation in a number of common research areas. Biomass supply has been considered one of these for many years. During 2011, WP1.2 representatives participated in a workshop focusing on transport issues in forestry held in Göteborg, Sweden. The implementation of large (60 and 90 ton) trucks has very important ramifications for the supply of biofuels.

Larger Research Applications supported by WP1.2

National and international research cooperation is a priority area for CenBio and WP1.2 has been active in the application process throughout the year. CenBio is used as the national anchor in such applications. In 2011 we were part of a successful consortium in an application to the Nordic Energy Fund 'Sustainable Energy Systems 2050'. The resultant project 'ENERWOODS' is coordinated by Denmark and includes numerous institutes in Sweden and Finland as well. The total budget is 14 M NOK. More information at http://www.nordicenergy.net/section.cfm?id=1-0&path=220,232

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Project highlights 2011

Productivity and costs of bundling roadside clearings

Clearing of roadside vegetation, mostly birch (*Betula spp*) provides a potentially enormous resource for the bioenergy sector in Norway. There are many challenges to utilizing this resource in a cost effective way, given that it is spread along the road verge in a narrow area. The study of a John Deere 1490 D Fiberpac bundler on three sites, compared the differences between using fresh or pre-dried whole trees for bundling, while the third considered the combination of whole trees and harvesting residues. The whole-tree bundles had a higher dry matter content than the mixed – generally 150-218 kg DM per bundled m^3. Depending on site, the productivity was 4.75-7.3 t DM per effective work hour. The costs of bundling were between 231 and 340 NOK t DM^{-1} (49-81 NOK Mwh^{-1}) while 50 km transport of bundles cost around 210 NOK t DM^{-1} (41-46 NOK Mwh^{-1}).

Figure 8: John Deere bundler in action (photo: Leif Kjøstelsen)

Belbo, H. & Kjøstelsen, L. 2011. Bunting av vegkantvirke: Produktivitet og økonomi. Rapport fra Skog og landskap 01/2012. 10pp. ISBN: 978-82-311-0150-5

A simulation approach to determine the potential efficiency in multi-tree felling and processing

This manuscript, which is currently in the peer-review process, considered the technical limitations to increasing the efficiency of multi-tree heads. In his PhD thesis, Helmer Belbo shows how the large proportion of crane time is detrimental to productivity when harvesting young stands for bioenergy. The ability of harvesting heads to accumulate multiple trees is essential. This study uses simulation to show both the importance of technical design, but also the potential gains from improved capacity and work method.

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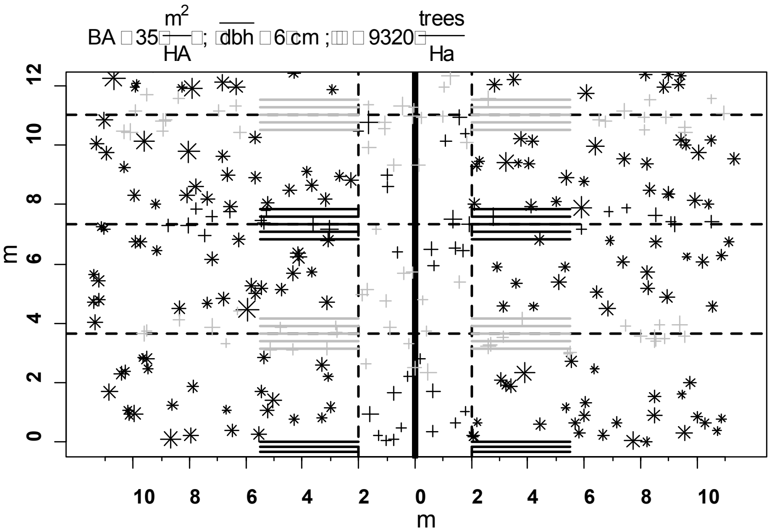

Figure 9: Image of forest stand generated in the simulation. Asterisks represent trees of various dimensions while lines represent harvested trees.

Belbo, H. 2011. A simulation approach to determine the potential efficiency in multi-tree felling and processing. In: Kühmaier, M. (ed) Proceedings of the 44th International Symposium on Forestry Mechanisation (FORMEC), 9th-13th October 2011. Graz, Austria.

Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees

This PhD thesis was supported during the final year by CenBio WP1.2 and was successfully defended in October 2011. Helmer Belbo's work, which dealt with efficiency improvements to the harvesting of small trees for bioenergy is central to WP1.2 and he will continue with work in this area as small trees constitute a considerable resource, and forest owners are seeking solutions to carry out silviculturally important thinning operations.

Belbo, H. Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees. Linnaeus University Dissertations No 66/2011. Linnaeus University Press.
ISBN 978-91-86983-08-6

Analysis of biomass supply systems

A method for determining the most efficient of a range of biomass production systems was presented at an international conference. Network or Critical Path Analysis is an operations research method that can be used to find the shortest or cheapest path through a network of alternative machine or machine system selection possibilities. In WP1.2, the further development of this method is 'work in progress' - in 2012 it involves developing the model in close cooperation with researchers in the 'Efficient Forest Fuels' research programme at Skogforsk in Sweden.

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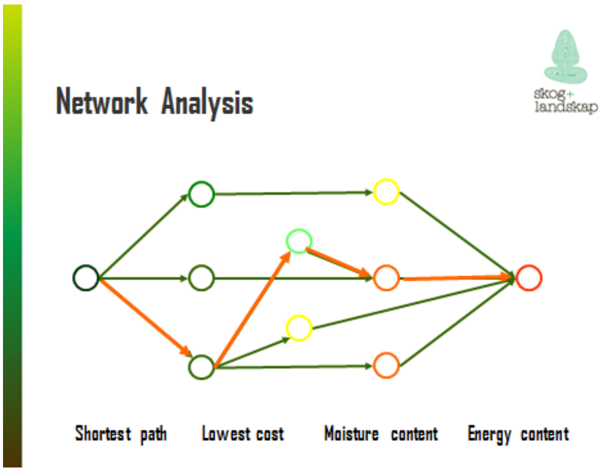

Figure 10: Schematic representation of the process of selecting the most efficient route through the network

Talbot, B., Søvde, N.E. & Suadicani, K. 2011. Using network analysis in configuring appropriate biomass supply systems. In: Ackerman, P., Ham, H. & Gleasure, E (eds.) Proceedings of the 4th World Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change , White River, South Africa, April 5-7, 2011. ISBN: 978-0-7972-1284-8.

Peer reviewed publications:

Belbo, H. 201?. A simulation approach to determine the potential efficiency in multi-tree felling and processing. *Silva Fennica* (in review - i.e. accepted with changes).

Belbo, H. & Iwarsson, M. 2011. Economic evaluation of accumulating felling and harvesting heads in energy thinning. In Belbo H. (2011). Efficiency of accumulating felling heads and harvesting heads in mechanized thinning of small diameter trees. Linnaeus University Dissertations No 66/2011. ISBN:978-91-86983-08-6.
(note: this manuscript will be submitted for peer-review in 2012).

WP1.3 Biomass and residue characteristics and quality

Biomass for energy purposes

In the future, it is both expected and desired that biomass will be classified by purpose. At the same time it is expected a competition for the different biomass types, as well as the feedstock prices might increase. For energy purposes the most suitable and affordable biomass types will be those with low quality and limited usability for other purposes. Low quality biomass types, however, imply challenges in a biomass-to-energy plant, as biomass properties influence the conversion processes and economics. The intention of WP1.3 is to investigate and overcome these challenges without increasing the conversion costs significantly. Although the biomass availability and quality will be a global issue, this task investigates mainly biomasses in a Norwegian context in order to serve Norwegian stakeholders.

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Figure 11: Different biomass qualities in Norway; wood chips (left) and branches (right) (photo: Eirik Nordhagen)

In 2011, combustion and storage of the different Norwegian biomass types were investigated. The results are published in acknowledged international journals. At the same time, investigation of the ash properties of different Norwegian woody biomasses was started in close cooperation between Norwegian Forest and Landscape Institute and SINTEF Energy Research.

Combustion experiments
Flue gas emissions and particle size distribution were investigated during combustion experiments of wood, forest residue and mixtures of these two. The combustion experiments were carried out in a grate fired multi-fuel reactor in SINTEF Energy Research laboratories. The selected fuels were virgin wood and forest residue (tops and branches) which are reflecting the main types of Norwegian biomasses recently and as expected in the future. Flue gas emissions and particle emissions were investigated, as the most important parameters in a combustion plant. The results reveal that:

- Due to higher nitrogen content of the forest residue samples, the NO_x emissions will increase.
- Air staging reduces the NO_x emissions with approximately 25%. This implies that further NO_x elimination methods need to be considered when the plant is fuelled by high amounts of forest residue feedstock.
- HCl emissions did not show a very clear trend, but they are generally reduced in staged experiments. Non-staged experiments show somewhat reduced HCl emissions for the mixtures which could be due to mixing effects or uncertainties in the measurements.
- The chlorine levels are low both in the fuels and therefore chlorine-induced corrosion is expected to be low in case of both feedstocks.
- SO_2 emissions show a clear fuel-S content dependence, the forest residue feedstock contains more sulfur, thus the higher SO_2 concentration in the flue gas.
- The particle emissions results did not show a clear trend although in case of the mixed fuels an increase in the smallest particles were observed.

The work was published in *Applied Mechanics and Materials Vols. 110-116 (2012) pp. 4564-4568*.

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Storage experiments
Converting solid biomass into pellets through densification greatly improves logistical handling and combustion processes. Raw material properties can affect pellet quality. This study investigated how storage and drying methods for wood used as a raw material for pellet production influenced pellet durability, bulk density and energy consumption. The results indicated that:

- Storage and high drying temperature of the raw material resulted in greater energy use during pelletization compared to drying at low temperature.
- Pelletization of the fresh material, dried at a low temperature, required low energy consumption and resulted in the highest durable pellets but low pellets density.
- The mild effect of low temperature drying on the concentration of extractives in fresh wood could be a contributing factor in improving the binding of pellets and retaining their lubricant effect in the pellet press. This could explain the negative correlation found between durability and energy consumption.

The work was published in *Fuel Processing Technology 92 (2011) 871–878*.

Ash content and quality investigations
This unique cooperation between Norwegian Forest and Landscape Institute and SINTEF Energy Research is coupling the knowledge at forest side and the combustion experience. It is known, that since biomass is a living organism it will change its mineral contents (ash content and composition) according to the growth conditions (soil, fertilization, pollution, precipitation and weathering). Ash content and composition is the main concern in to biomass-to-energy utilization as it is influencing practically the whole conversion process. At the same time ash is related to the corrosion and fouling problems in a biomass-to-energy plant which can lead to undesired shut-downs and increased costs. This task will establish knowledge about biomass (ash) qualities of the biomasses grown in Norway. The work was started in 2011 and the results will be published in international journals in 2012.

WP1.4 Residues upgrading and use

The Norwegian goal for increasing the energy production from biomass, leads to the production of about 70 000 metric tons bio ash per year, roughly estimated.

Some abbreviations used in this section:

BWA	bottom wood ash
Ca	Calcium
K	Potassium
MBM	meat and bone meal
N	Nitrogen
NPK	nitrogen, phosphorus, potassium
P	Phosphorus
UMB	Universitetet for miljø- og biovitenskap

In this WP research on utilization of wood ash and anaerobic digestates has been given priority, and the research on ash utilization has so far been the major activity. Our approach has been combination of different waste streams containing different plant nutrient in order to make recycled NPK fertilizer. The first results was published in the book “Recycling of Biomass

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Ashes", Springer Verlag 2011, showing the possibility of combining bottom wood ash (BWA) and meat and bone meal (MBM) as NPK fertiliser. Unlike use of BWA in forestry, BWA for use on agricultural land should have high solubility and rapid release of plant nutrients.

Important release of plant nutrients from ash

Figure 12: Barley pot experiment with N level 180 kg N ha^{-1}: Calcium nitrate + BWA (left), calcium nitrate (right) (photo: Trond K. Haraldsen)

A new series of pot experiments were carried out in 2010 and 2011, combining different organic waste types alone and in combination with BWA (see Figure 13). It was found that BWA with high concentration of K and relatively low concentration of Ca was suitable for mixing with organic N rich waste types, as the rise in pH level was moderate. The most surprising result was that BWA not only supplied plant available K, but also had significant effect on P supply to the cereal crop. As neither calcium nitrate nor BWA alone gave significant effects compared to unfertilized sandy soil, calcium nitrate + BWA gave very good plant uptake of N, P and K (see Figure 12). The results from these investigations were presented at a Nordic seminar for agricultural scientists (NJF-seminar 443 "utilization of manure and other residues as fertilizers", Falköping, Sweden, November 2011) and at ASH 2012 in Stockholm in January 2012. These results will be further dealt with in scientific papers, which will be submitted in 2012.

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Figure 13: Barley pot experiment. From left: control, unfertilized; NPK fertilizer (160 kg N ha^{-1}); Calcium nitrate +BWA (160 kg N ha^{-1}), MBM+BWA (160 kg N ha^{-1}) (photo: Trond K. Haraldsen)

A master thesis at UMB based on the same approach was delivered in December 2011 "Combined waste resources as NPK fertiliser: Results from a pot experiment". In this experiment on a sandy loam soil of morainic origin, rye grass was the crop. This experiment also indicated a significant effect of BWA on P supply, showing that combination of BWA and MBM may lead to significantly elevated levels of readily available P (P-AL) in soil after harvest. Other N rich organic waste materials as composted fish sludge from salmon hatcheries gave equally high plant yields as MBM, and less elevation of P-AL in the soil after harvest.

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

Regulations for use of ash

Ash has mainly been landfilled in Norway, and is therefore mainly treated as waste material. In EU the work on new classification of waste may be a problem, as it is suggested that strongly alkaline and corrosive waste materials should be categorized as hazardous waste. Both the coal and bio energy industries are working against this classification. It is true that some coal fly ashes, as well as some other ashes from wood, peat and biomass, have high calcium content and produce a leachate with a pH in excess of 11.5. This, in turn, is a result of the high calcium content of the coals/fuels from which they have derived, and is a natural phenomenon which occurs for example in forest fires. On the other hand ash from clean wood and other clean biomass residues can be applied in organic farming in the EU, as in that regulation the origin of the materials is more important. As stated by one speaker at ASH 2012, it can be hard to find good arguments for application of materials in agriculture that is classified as hazardous waste by one set of directive, and as useful products in other regulations.

The high pH in ash makes the material interesting as liming agent. The ash composition is also similar to that of Portland cement; used as a raw material in cement production, the reductions in the CO_2 emissions from the plant can reach about the same magnitude as the ash input.

Use of ash in construction works and road building are relevant also in Norway, but regulations have not been implemented. Similarly recycling of wood ash in forestry is not permitted in Norway, and the regulations for use of ash in agriculture and urban greening is based on concentrations of heavy metals on dry matter basis, which strongly limit the possibilities for utilization of ash based products. Analyses of different ash types from Norwegian bio energy plants show that there are large variations in quality between different plants, partly due to different technologies at the plants and partly due to use of different fuels. This material is very important for the work on relevant regulations for ash utilization in Norway. There are also indications that some types of biomass with high contents of chloride and alkali metals cause corrosion in the boilers and corroded metals may end up in the ash. This should be further studied in CenBio in order to make guidelines for fuel qualities needed for stable operation at the biomass plants, also giving a recyclable ash quality.

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SP2 Conversion mechanisms

Energy from unexploited resources

Bioenergy is like a Kinder Egg; it gives us three gifts at the same time: CO_2-neutral heat and electricity, wealth creation in rural Norway and the opportunity to utilise resources that would otherwise be wasted. In order to increase the use of bioenergy, we are addressing the toughest challenge there is in the field: the exploitation of low-grade biomass – affordable resources from which energy is technically difficult to produce.

Norway has set itself the goal of doubling bioenergy production from 14 to 28 TWh between 2008 and 2020. However, virgin biomass (such as timber), is a costly fuel for which many sectors are fighting (e.g. the paper, construction and bioenergy industries, etc.). In order to be able to reach the 2020 bioenergy goal, a significant portion of biomass-to-energy plants will need to be able to handle such challenging fuels.

"Challenging biomass" is a term that covers a wide variety of fuels, including forest and agricultural residues (such as branches and tree-tops, straw, etc.) as well as food waste and sewage sludge. These resources are largely unexploited in Norway today. CenBio is doing research on means of increasing the energy efficiency and reducing the environmental impact (emissions) associated with the use of such fuels.

We are looking into all the main conversion processes, i.e. combustion, gasification, pyrolysis and anaerobic digestion. Two good examples of our work are the production of a novel biomass fuel, namely green coal, and the improvement of biomass properties through the torrefaction process (see WP2.1 and WP2.3 for more details).

All our activities have one common denominator: they are contributing to the increased production of bioenergy in Norway in an efficient, environmentally friendly and profitable way.

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

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WP2.1 Combustion

CenBio fights the everyday challenges of running BtE plants

Being able to efficiently use challenging biomass fuels (straw, branches and tops, agricultural residues, forest residues, etc.) to produce bioenergy is a top priority to make this sector profitable and therefore significantly contribute to the bioenergy production in Norway. In this way, the bioenergy sector will:

1. Face less competition from other industries (paper, materials, furniture, etc.) as with timber
2. Get access to affordable fuels
3. Turn unused by-products into valuable and renewable energy

However, using such challenging fuels is not without problems especially because of the nature and amount of the ash-forming elements in these biomass fuels. The main challenges are:

1. Corrosion where metal surfaces are chemically attacked and "eaten" away, forcing their frequent and costly replacement
2. Slagging where big metallic lumps are formed in the combustion chamber and therewith disturb or even stop the combustion process
3. Fouling where deposits disturb the gas flow in the plant and hinders heat transfer

Figure 14 shows a corroded superheater tube of a biomass boiler tube after only two years of service and speaks a thousand words.

Figure 14: Corroded superheater tube from a biomass boiler (jenkins.ucdavis.edu).

How can these issues be avoided or at least reduced to an acceptable level to ensure optimal operation and profitability? This is the challenge this work package has taken up.

The method investigated is the use of so-called additives in biomass burning boilers. Additives are chemical compounds which may affect the overall chemistry taking place during combustion in order to prevent corrosion, fouling and slagging from happening. For example, corrosion is mainly provoked by gaseous potassium chloride; by reducing the amount of potassium chloride formed during combustion one can reduce the corrosion severity. This can be done by "forcing"

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potassium into reacting with additives to form inert compounds such as potassium aluminosilicate.

The study carried out was focused on the experimental investigation (laboratory scale) of a class of chemicals called zeolites together with barley husk and wheat straw, two challenging biomass fuels. These compounds are aluminosilicates and have barely been investigated before but they appear very promising mainly because of their 3D "honeycomb" structure (see Figure 15) which allows for the easy capture/entrapment of potassium. Furthermore, zeolites are commonly used in detergents and end up in sewage sludge which can be seen as a very affordable source of these compounds.

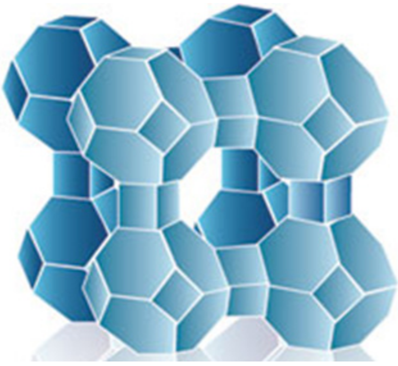

Figure 15: Schematic representation of the honeycomb structure of a zeolite (zeoliteguide.com).

To evaluate the efficiency of zeolites to prevent corrosion, slagging and fouling, a battery of advanced analytical tests were employed, including scanning electron microscopy, energy dispersive spectrometry and X-ray diffraction. The laboratory-scale experiments confirm that zeolites are able to fight the challenges associated with challenging biomass fuels. For example, Figure 16 shows the X-ray diffraction pattern of the combustion products of zeolite with the corrosive alkali chloride. The specific peak pattern marked (a) indicates the presence of the inert compound KAlSiO4 (alkali aluminosilicate), a largely inert compound.

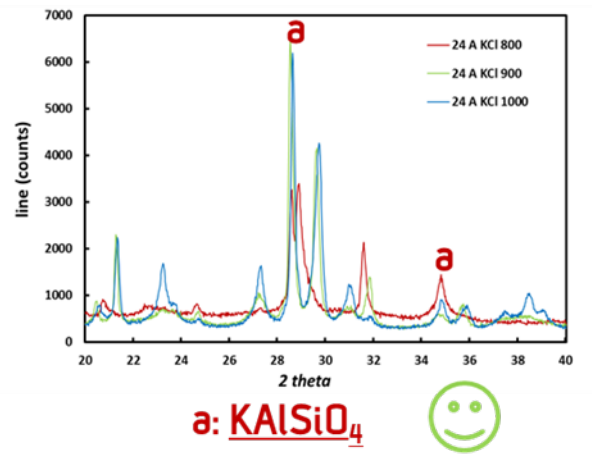

Figure 16: X-ray pattern of the combustion products of zeolite and corrosive potassium chloride at 800, 900 and 1000°C.

This extensive work has been submitted as a scientific article to Energy & Fuels, an internationally renowned scientific journal published by the American Chemical Society.

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WP2.1 also includes participating in IEA Task 32, Biomass Combustion and Cofiring.

WP2.2 Gasification

One process, many possibilities

The main effort was focused on active participation to IEA (International Energy Agency) Bioenergy Task 33 "Thermal gasification of biomass". IEA Tasks are a unique forum to monitor technical (and non-technical developments), exchange information and promote cooperation to maximize synergies and avoid parallel activities. Participation in such a network is a must to stay at the forefront.

As stated on the Task 33 website, the ultimate objective is to promote commercialization of efficient, economical, and environmentally preferable biomass gasification processes for:

- the production of electricity, heat, and steam
- the production of synthesis gas for subsequent conversion to chemicals, fertilizers, hydrogen and transportation fuels
- the co-production of these products

Figure 17 clearly illustrates the many possible applications of the gasification products.

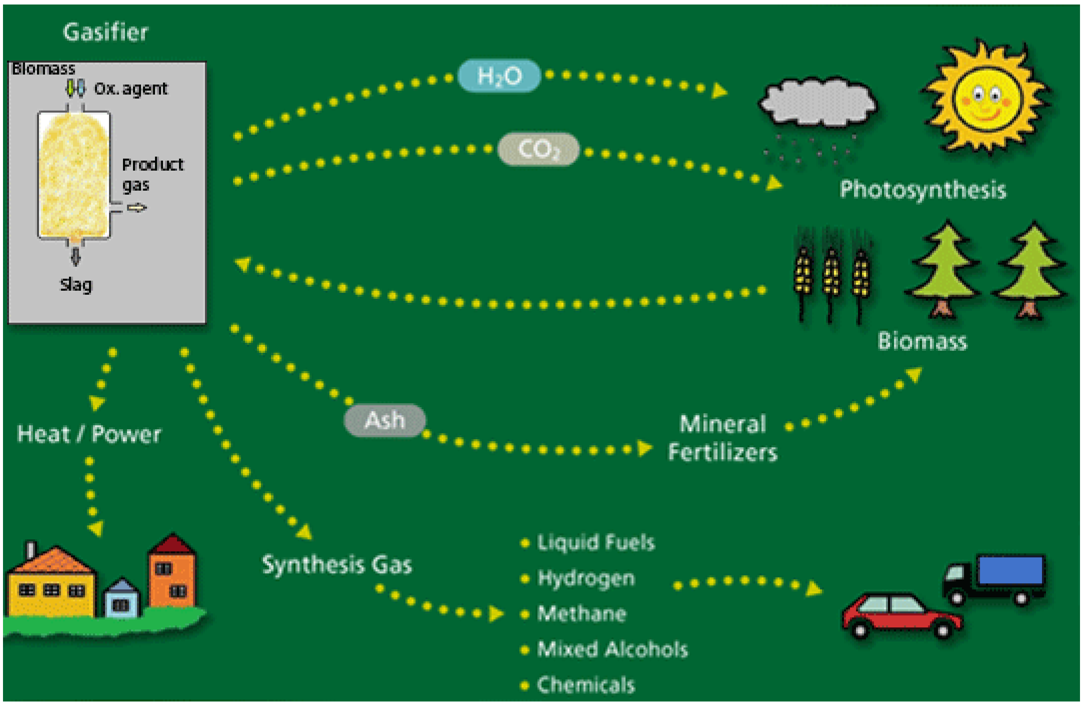

Figure 17: Gasification products applications (IEA Bioenergy Task 33 website).

The hot topics discussed in the last 3-year period include:

1. Advanced biofuels
2. Small scale biomass co-generation: technical status and market opportunities
3. Gasification and alternative fuels development
4. Biomass gasification opportunities in the forest industry

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WP2.3 Pyrolysis

CenBio develops the ultimate solid biomass fuel

It is widely expected that the main contribution of new bioenergy in Norway will take place in small-scale appliances for domestic heating. However, biocarbon (also called biocoal or charcoal), a renewable solid with superior properties, may significantly modify this picture and contribute to a significant increase in bioenergy production. Enabling the biocarbon value chain (see Figure 18) from challenging fuels will have a twofold effect:

- Get rid of the challenges associated with their handling and combustion and
- Give an energy product with high added value from inexpensive and largely unexploited resources

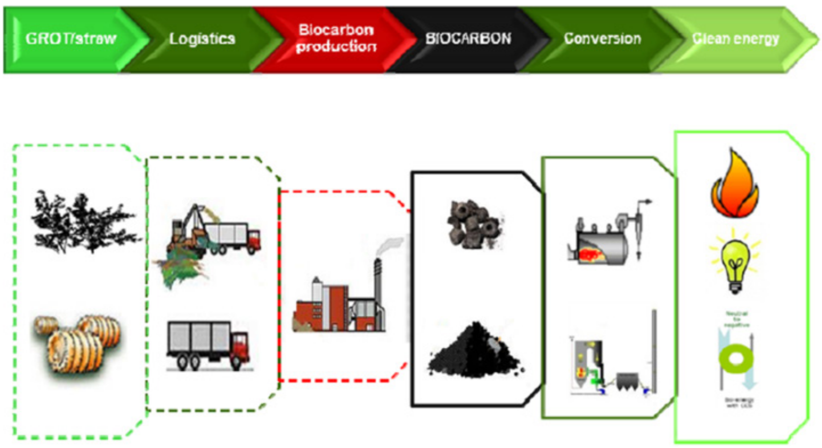

Figure 18: The biocarbon value chain

Biocarbon has unique properties as a fuel in combustion applications. It is the ultimate solid biomass fuel with a

- higher energy density and better homogeneity than virgin biomass (see Figure 19)
- lower ash content and lower contents of N and S than anthracite

This gives unique possibilities with respect to stable combustion and emission control. Biocarbon can easily be crushed and used as powder, pellets and briquettes.
There are three main expected energy applications for this novel fuel:

1) Substituting fossil oil in small-scale heating and CHP plants, especially peak load use,
2) Abatement of operational problems and emission reduction in small-scale heating and CHP plants,
3) High efficiency and low emission domestic heating. This innovative value chain is therefore of great interest to several industrial actors in Norway and abroad from the forest sector to energy users and producers.

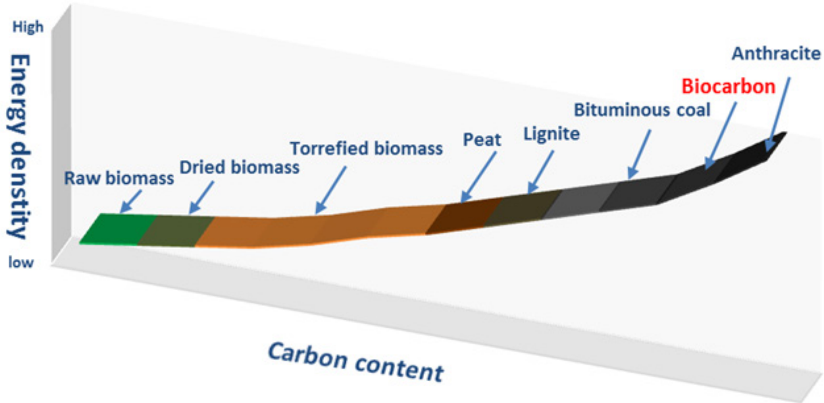

Figure 19: Energy density as a function of carbon content

In this work package, the optimal production of biocarbon (also known as carbonization) using biomass by-products is studied experimentally using advanced thermal methods and a variety of analytical laboratory tools (microscopy, etc.). The work is a cooperation between SINTEF Energy Research, NTNU, the University of Belgrade and the University of Hawaii at Manoa. Professor Michael J. Antal Jr. at the University of Hawaii is central and is a leading world expert on biocarbon, ensuring that the work carried out is at the frontline of research.

The activity in CenBio is pursuing two axes: studying the parameters influencing the production of charcoal from problematic biomass fuels as well as the understanding of the processes taking place. The work was published as a peer-reviewed article in Energy & Fuels, an internationally renowned journal (level 2) under the title *Is Elevated Pressure Required To Achieve a High Fixed-Carbon Yield of Charcoal from Biomass? Part 1: Round-Robin Results for Three Different Corncob Materials* (Energy Fuels 2011, 25, 3251–3265).

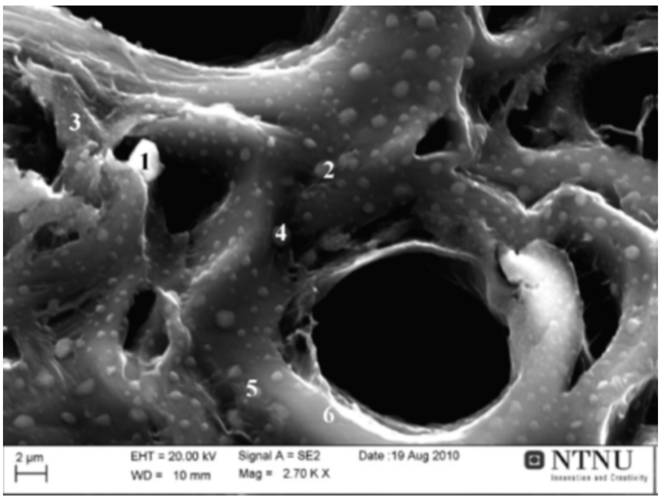

Figure 20: Charcoal produced at high pressure.

The main findings of this work show that high pressure can be used to increase charcoal yield, and brings much needed insights about the reactions leading to this increase. Figure 20 (microscopic picture) shows the presence of carbon-rich tiny balls in the charcoal structure produced at high pressure. These tiny balls prove the importance of vapour-solid interactions at high pressure.

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Future efforts will focus on new biomass feedstock to further expand the range of usable biomass fractions.

WP2.4 Anaerobic Digestion

Increased energy from anaerobic digestion

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

The main benefit of anaerobic digestion is, however, that it offers an attractive option for treatment of degradable organic wastes. At the same time emissions of greenhouse gases is lowered, and recycled organic based fertilizers is generated.
In Norway anaerobic digestion has so far mostly been used for treatment of waste water treatment sludge, but has recently attracted more attention as a way to produce renewable energy from manure and other organic waste streams. A political goal has been set to treat 30% of the manure by anaerobic digestion within 2020.

Most biogas processes produce far less methane than would be expected from theoretical considerations based on the chemical composition of a given substrate. CenBio aims to increase the amount of renewable energy from AD and at the same time assure a digestate quality that maintains necessary recycling of nutrients. CenBio is working towards this goal by:

1. ***Broadening the spectrum of feedstocks.*** Manure and domestic organic wastes are commonly used feedstocks for AD. To produce more energy, more organic material must be made available for AD processes. CenBio is currently identifying available streams of organic materials, and has demonstrated that a typical Norwegian waste stream like fish ensilage may be co-digested with manure at a higher rate than previously expected. The mixing of different substrates may also improve the residues quality as fertilizer. Also, with the help of pre-treatment (see Figure 21), other more recalcitrant lignocellulosic materials are potential substrates for biogas production.

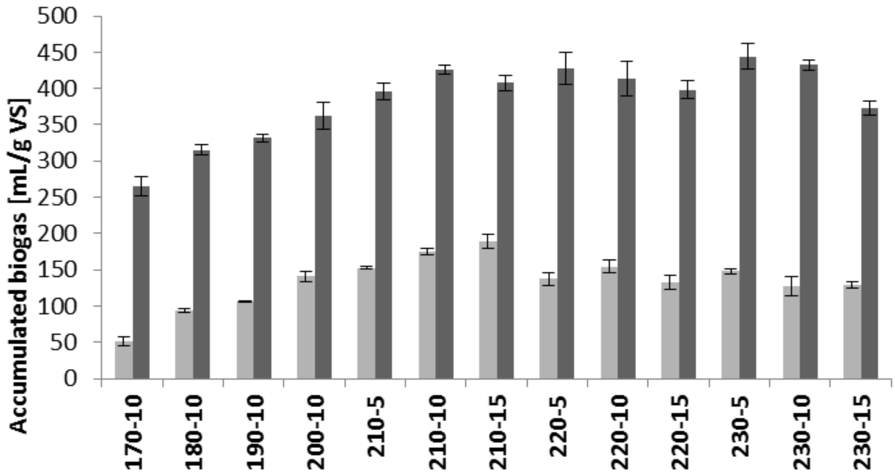

Figure 21: Biogas production as a function of pre-treatment. Light grey, 11 days, dark grey, 57 days.

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2. ***Improve digestibility.*** Digestibility of organic materials may be increased by enzyme treatment, maceration, hydrolysis, microorganisms etc. Horn et al. recently presented a study on *Biogas production and saccharification of Salix pre-treated at different steam explosion conditions* in the internationally respected journal Bioresource Technology (DOI: 10.1016/j.biortech.2011.06.042). Their study demonstrated an increased biogas yield from Salix chips after pre-treatment by thermal hydrolysis (see Figure 21). This study also spotted a correlation between enzymatic sugar release and biogas yield, a correlation that may be used to predict biogas yield of pre-treated biomass fractions using an enzyme assay.

3. ***Improve fertilizer quality of digestate***. In field studies we have demonstrated that digestate have comparable fertilizing effect on cereals as do mineral fertilizer. The water content of digestates is, however, normally quite high. We are currently conducting promising experimental studies on innovative technologies to reduce the liquid volume, while retaining and tuning the fertilizer value of the digestate. The on-going research is expected to significantly reduce costs and to facilitate storage and transport of digestate for fertilizer purposes.

High quality research requires modern and adapted laboratories. Staged by the Norwegian Centre for Biogas Research, The Norwegian University of Life Sciences and The Norwegian Institute for Agricultural and Environmental Research – Bioforsk has established a state-of-the-art AD research laboratory, containing 24 laboratory reactors (8-10 L) with sophisticated monitoring and control systems which allows research to be performed at a high international level. The new laboratory was opened in in January 2012 by the Minister of Agriculture (see picture below).

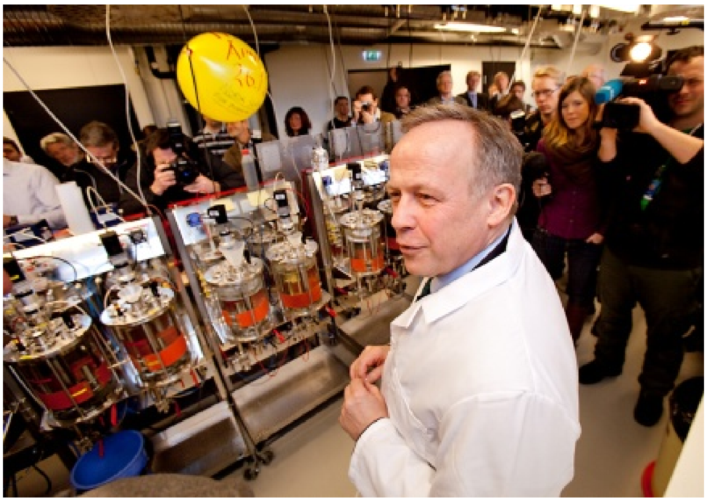

Figure 22: Minister of Agriculture and Food Lars Peder Brekk opens the new biogas laboratory (photo: Håkon Sparre)

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

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Aalborg University. The establishment of our successful team of around 30 highly motivated researchers has been propelled by a close link to the industrial partners of CenBio, especially the commitment of Cambi pushes the CenBio research towards innovative technological solutions based on steam explosion pre-treatment and biochemical understanding of anaerobic digestion. Cambi is strongly research-oriented and was awarded the Bioenergy Innovation Award by CenBio in 2012 (see picture below). CenBio is a cornerstone in the development of a Norwegian centre for research and education on anaerobic digestion.

KMB STOP: WP2.5 Torrefaction

STOP (STable OPerating conditions in biomass and biomass residues combustion plants) is a competence building project financed by the Research Council of Norway (RCN) and the FME CenBio industry partners, and has an annual budget of 3500 kNOK and runs for 4 years (2010-2013). In FME CenBio, STOP is strongly linked to WP2.3 Pyrolysis, WP1.3 Biomass and residue characteristics and quality, WP2.1 Combustion, WP2.2 Gasification, and as well to the WPs of SP3 – Conversion technologies and emissions.

The overall objective of STOP is to establish an internationally oriented Norwegian competence base in the area of biomass torrefaction for stable operating conditions in biomass and biomass residues combustion plants.

Briefly explained, torrefaction is a mild-pyrolysis process (200-300 °C) that can be employed as a pre-treatment/upgrading step to improve properties of biomass fuels. The treatment can result in not only increased energy density, but also enhanced grindability, better homogeneity and better storage and transport characteristics for biomass fuels.

During 2011, the main focus has been on 1) erection of a torrefaction reactor in SINTEF laboratory in Trondheim and 2) detailed studies on the properties of torrefied fuels.

The reactor is composed of the following elements (see Figure 23):

- Bin for raw material (green top bin)
- Feeding screw
- Drying conveyor (top purple cylinder)
- Heating conveyor
- Torrefaction conveyor (lowest purple cylinder)
- Sliding feeder between conveyors
- Product container (metal bin on the floor)
- Piping
- Instrumentation
- Electrical and cabling

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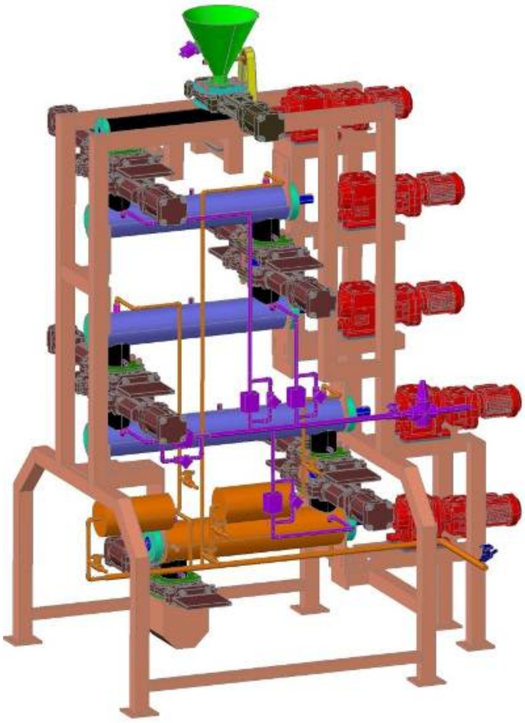

The torrefaction reactor pictured in the laboratory in Trondheim on the day of delivery

Figure 23: The torrefaction reactor: 3D scheme and picture in the SINTEF laboratory. (photo: SINTEF)

The reactor is designed with broad parameter flexibility in mind. It will be able to process a wide variety of fuels and fuel sizes. In addition, the different temperature zones are controlled independently. The setup will be fully automated allowing a complete control over all the inputs and outputs of gases and solid materials. The setup will also be fully instrumented in order to have a complete characterization of the product gases from all the high temperature zones. The liquids produced during torrefaction will be collected for off-line characterization.

In 2011 the work has concentrated on carrying out experiments and analyses that will be presented and discussed in two journal publications.
The first one focus on producing different torrefied materials in a macro-TGA with variations in

- fuel types (soft- and hardwood)
- holdup time in torrefaction zone (30 and 60 minutes)
- particle size (cubes of 1x1 and 4x4 cm)
- torrefaction temperature (225 and 275 °C)

16 different types of torrefied materials were produced. The produced fuels have been characterized in terms of physical and combustion properties. The measurements included proximate and ultimate analysis, heating value, hydrophobicity (the fuel's ability to resist water absorption), grinding energy requirements and particle size distribution of the grinded materials. In addition, the produced gas from all the experiments was measured with a FTIR spectrometer and a Gas Chromatograph. A partial stream was also cooled down to –50 °C in order to collect the liquid fraction.

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The produced fuels from the macro-TGA were used in the second publication, focussing on combustion kinetics studies in a micro-TGA. In addition, surface area measurements which also influence the reaction rates of combustion were performed. Figure 24 below shows the product distribution for the 16 macro-TGA experiments, and clearly shows the influence of temperature, holdup time, particle size and fuel type on the product distribution.

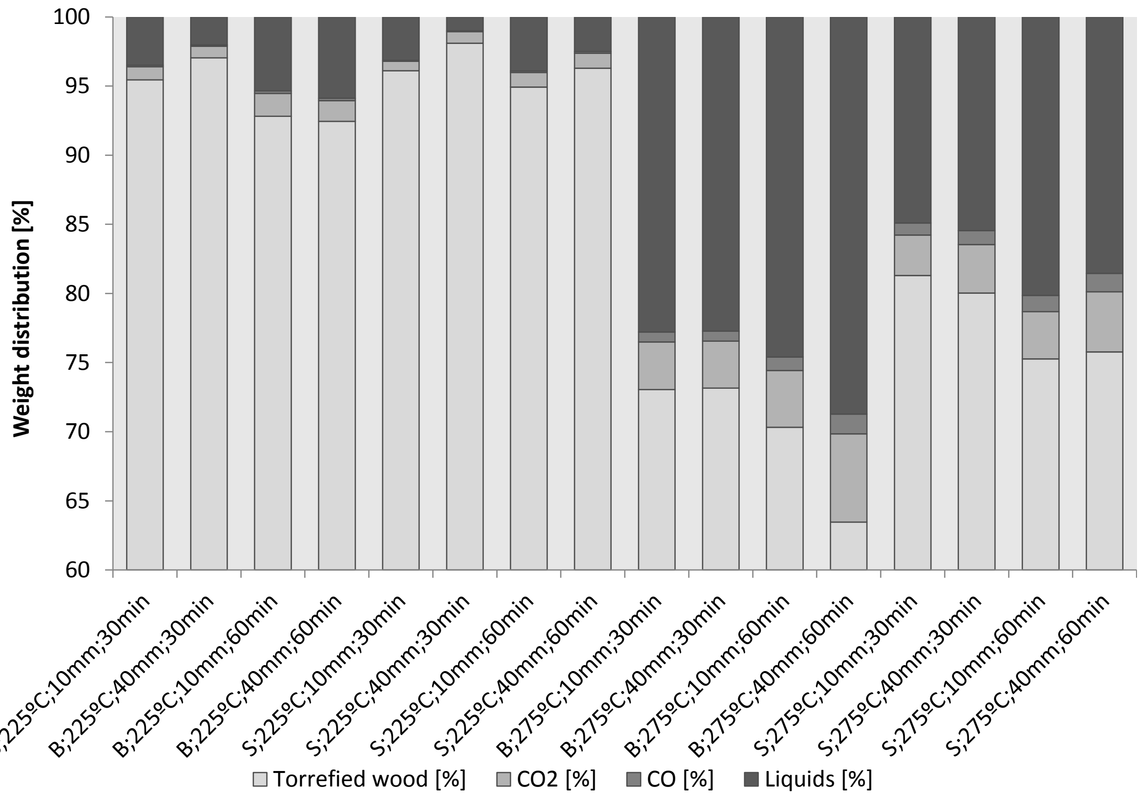

Figure 24: Product distribution in weight % relative to the initial mass. B: Birch, S: Spruce

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SP3 Conversion technologies and emissions

Clean log combustion and bioelectricity

Wood stoves account for an important part of energy consumption in our wintery country. As a part of the bioenergy effort, the government expects that Norwegians will use even more wood in the future. CenBio intends to contribute to efforts to meet this goal while ensuring that this happens without degrading local air quality. At the same time we will contribute to more efficient electricity generation from biomass in combined heat and power (CHP) plants, with minimum emissions.

Every second kilowatt-hour of heat generated from biomass in Norway comes from burning logs. The goal of doubling the use of biomass for bioenergy in Norway by 2020 includes doubling the use of logs. The need to maintain air quality in densely populated areas means it would be unwise to increase the use of logs without reducing particle emissions from wood stoves. CenBio's efforts in this field are therefore of great importance.

The current requirement is that new wood stoves must emit less than 10 g particles per kg dry wood burnt. Our research will reduce particle emissions to 2.5 g in future stoves while making stoves more energy-efficient, in order to ensure more sustainable use of our biomass resources.

Norway has only marginally increased its electricity generating capacity in recent years, while electricity consumption has steadily risen. Biomass-fired CHP plants will therefore be welcome for their ability to provide green electricity. However, only cheap biomass fuels, such as waste wood and residues from forestry and agriculture, will make such plants economic in Norway given today's framework conditions. Because cheap fuels are also more difficult to handle and use, we are improving combustion technologies and methods that will convert these to electricity in a cost-effective way.

Biomass combustion also produces harmful NOx emissions, and we are making strenuous efforts to reduce these. This will be among our most important contributions to making Norwegian bioelectricity completely green.

Øyvind Skreiberg
Leader of Conversion technologies and emissions
(photo: SINTEF)

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Objective: To demonstrate that all the energy conversion efficiencies listed in the CenBio Vision 2020 are practically and economically feasible, as well as environmentally benign.

In the Small-scale (stove) segment (WP3.1) energy efficiencies of 0.85 will be demonstrated for selected fuel fractions, not as peak efficiencies, but as average efficiencies including cold-starts. In the District Heat segment (WP3.2), 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. In the Heat and Power segment (WP3.3) the feasibility of efficiencies of 0.95 will be demonstrated for the combined production of heat and power. In the final Emissions work package (WP3.4) it will be demonstrated how emissions from plants converting biomass to energy may be reduced to below the half of present regulations.

Innovations from this subproject 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 Wood / pellet stoves

Radical emissions reduction and efficiency increase

Small-scale wood combustion in wood stoves accounts today for half of the bioenergy use in Norway (about7 TWh in 2010), and the use of wood logs in small-scale units and pellets in pellets stoves is expected to increase substantially towards 2020.
The goal of this work is to increase the energy output from those units with 10 TWh within 2020 (see Fig 1-1). 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 this WP 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 increase substantially over the next decade, it is important to ensure that harmful emissions such as particles are minimised, and that national requirements and regulations are uphold and improved, not relaxed due to new EU directives not taking into account the special Norwegian conditions. Partial load performance is very important since firing at partial load will be the typical situation in Norway. Standardisation of testing methods is then a key issue, through active participation in the international standardisation work related to new EU directives.

Development and testing of new and improved combustion chambers and solutions for improved combustion and reduced emissions caused by incomplete combustion is a key WP activity. The focus is primarily on various types of wood stoves (including light heat storing units), but also

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fireplace inserts, pellet stoves and combined units. Key aspects are efficiencies, cost-efficiency, emissions, fuel flexibility, fuel quality and user-friendliness.

During 2011 the experimental activity focused on innovative methods for increasing the thermal efficiency due to improved convective heat transfer solutions for the exhaust gas after the combustion chamber. Three heat transfer solutions for light heat storing stoves were tested. The most effective solution is to force the flue gas flow close to the outer wall of the heat transfer section, by inserting a closed box in this section, thereby increasing the flue gas flow speed and the convective heat transfer coefficient. The construction can increase the average heat output during the first hour up to 45%. Figure 25 illustrates the concept.

Figure 25: Improved heat transfer concept. (photo: Inge Saanum, SINTEF Energi AS)

WP3.2 District heat

Networking is part of the solution

Being an active part of national, European and international networks is not an option but a necessity for any industry sector in order to

1. Stay updated about the latest developments and best practices
2. Exchange information and experience
3. Work towards common goals with one strong voice, especially towards authorities

Through CenBio participation, industrial partners are benefiting from no less than three networks in this work package:

1. IEA (International Energy Agency) Bioenergy Task 36 - Integrating Energy Recovery Into Solid Waste Management Systems
2. PREWIN (Performance, Reliability and Emissions Reduction in Waste Incinerators) European Network [not discussed further here]
3. Avfallsforsk, a national initiative [not discussed further here]

The overall IEA Bioenergy Strategic Plan is:

- Promote market deployment of technologies and systems for sustainable energy generation from biomass
- Share information between participating members

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- Stimulate interaction between RD&D programs, industry and decision makers
- Assist non-participants in adopting appropriate waste management practices
- Identify opportunities to work together with other Tasks and to identify joint events and projects to improve synergy and avoid duplication
- Identify and interact with appropriate international organizations

Concerning Task 36, the specific activities for the 2010-2012 triennium (not exhaustive) are:

a) Review the impact of changing policy on deployment of Energy from Waste

b) Review methodologies for assessing the biogenic content of solid waste

c) Examine LCA of waste management and energy recovery options, with particular reference to the carbon aspects

d) Examine options for integrating energy recovery from waste into recycling and recovery waste management facilities in order to explore the practical aspects of the eco refinery concept (I-AWARE: Integrated Advanced WAste REfinery)

e) Review small scale options for energy from waste recovery that are particularly suited to rural areas and developing nations

f) Review the management of the residues from energy recovery

These activities were selected by the member countries after discussions with the relevant national actors and reflect therefore the hottest R&D themes on an international level.

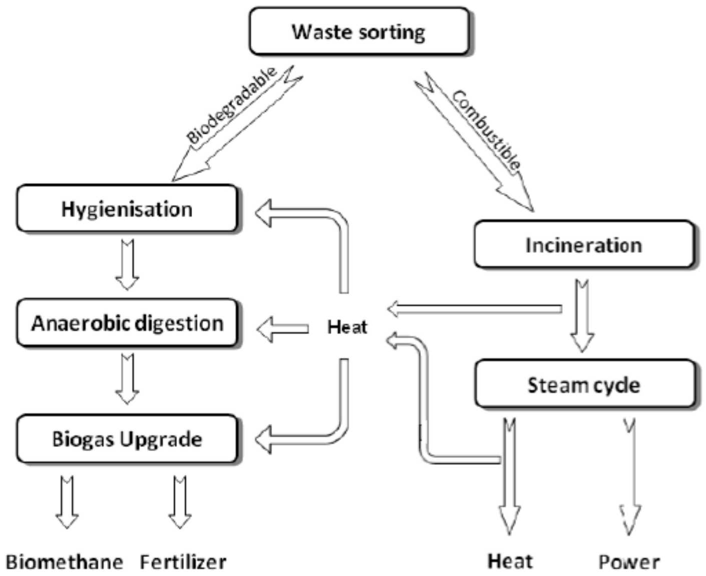

Figure 26: I-AWARE concept #1

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Going into more details concerning activity d) waste/eco refinery, Figure 26 and Figure 27 present two I-AWARE concepts among several investigated in IEA Task 36. While the first one can be said to be readily achievable, the concept presented in Figure 27 includes much more advanced components and processes. However all concepts seek to achieve the same overall goal: advanced multi-products systems where all mass and energy flows are utilized as efficiently as possible.

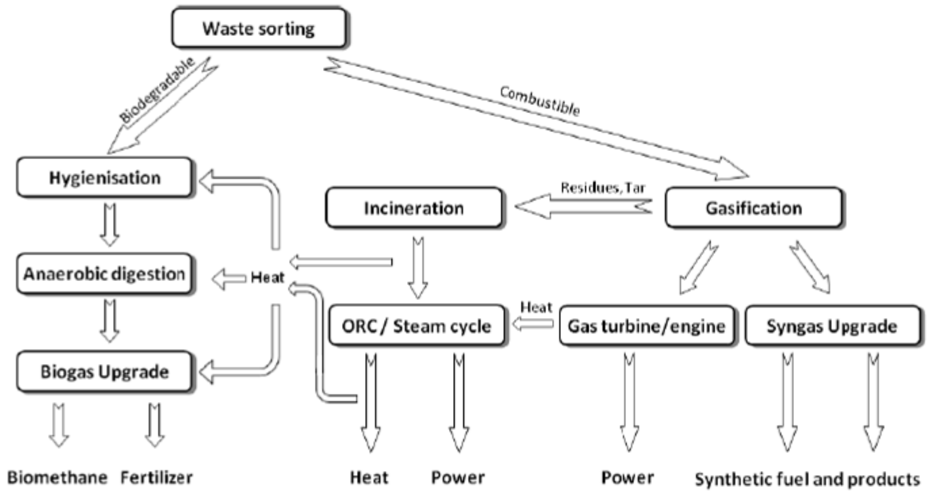

Figure 27: I-AWARE concept #2

Another important work performed in this work package is the monitoring of the implementation of the new EU waste directive in Norway as well as its practical implications for the industry.

An important new regulatory element is the so-called R1 energy efficiency formula (see Figure 28) which determines the classification of waste incinerators into two categories either as *recovery* (R1>0.60 or 0.65 depending on the age of the installation) or *disposal* (R1<0.60 or 0.65) installations. This may have important consequences for the waste branch in the near future.

What will happen in Europe and Norway after the implementation of R1? The main goal of this formula is to promote the highest energy use in waste incinerators both internally and externally and will hopefully have exactly this effect. In Norway most installations are expected to reach the highest classification (recovery); however, the practical implementation of the R1 calculation is rather complex and might be time-consuming, especially the first year.

$$\text{Energy Efficiency} = \frac{(E_p - (E_f + E_i))}{(0.97 * (E_w + E_f))}$$

In which:

E_p	The annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (GJ/year)
E_f	The annual energy input to the system from fuel contributing to the production of steam (GJ/year)
E_i	The annual energy imported excluding ,E-w and E-f (GJ/year)
E_w	The annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)
0.97	The factor accounting for energy losses due to bottom ash and radiation

Figure 28: The R1 energy efficiency formula

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

Industrial biomass heat based on combustion of forest/wood residues is important in e.g. the paper and pulp and the wood processing industry, while MSW is important in waste-to-energy plants. In both cases, there is a potential for significant improvements. It is important to 1) 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, and 2) assess the potential for emission reduction through efficiency improvements, fuel modifications and operational changes.

Several technology options exist for CHP plants (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. Also 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 important to assess the suitability of the existing technologies and the potential for further improvements with respect to cost-efficiency and emission abatement, including framework conditions, and operational optimisation. In 2011 a study on optimum technologies for medium to large scale biomass and MSW combustion and gasification CHP plants was carried out. The main conclusions are:

- Fuel related challenges causing operational problems and contribute to agglomeration, sintering, slagging, fouling, corrosion and emissions are to a large extent influencing the cost-efficiency of a biomass CHP plant, both for combustion and gasification based CHP plants. In principle, the choice of fuel, conversion technology and CHP technology cannot be made independently; they belong to a system that has to fit together.

- Different CHP technologies exist; however, steam turbines are very much dominating for medium to large scale biomass CHP plants based on combustion. Gasification gives some advantages connected to e.g. achievable electric efficiency and gas cleaning possibilities before combustion. However, gasification can still not be considered a fully commercial technology for biomass or MSW.

- The cost-efficiency improvement options for biomass CHP plants are many, since there are a number of factors influencing a plant's cost efficiency. The fuel is often the single most costly input factor, however, most challenges connected to operation and maintenance of biomass- and MSW- CHP plants are connected to the fuel quality. Hence, money saved on utilizing a cheaper fuel cannot lead to an equivalent cost increase for operation and maintenance of the plant.

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- Hybrid cycles (cycles using two different conversion technologies) can significantly increase the overall electric efficiency for a plant, but for e.g. gasification based hybrid cycles the gasification process and the gas cleaning requirements is a weak link. The amount of heat that can be extracted from plants where a maximum electric efficiency is a goal is low or zero. CHP plants must in practice be tailored for covering a heat requirement.

- Regulatory and framework conditions are heavily influencing biomass- and MSW- CHP plants cost-efficiency. Hence, improving the framework conditions with regards to the electricity generating part of a CHP plant is very important for the future expansion of biomass based electricity generation in Norway.

In a longer-term perspective, standalone electricity generation from biomass and MSW in Norway may become a cost-efficient option. It is therefore important to evaluate available technologies for standalone electricity generation from biomass and MSW and to suggest optimum technologies for Norwegian conditions.

ChlorOut is a corrosion and fouling reducing concept for biomass fired boilers as well as for NOx, CO and dioxin reduction. The use of ChlorOut in waste wood, demolition wood and waste residue fired boilers are not fully developed. Tests will be done in the Jordbro-plant (see Figure 29), south of Stockholm, in cooperation with Vattenfall AB, BU Heat. The plant is a BFB, 63 MW_{th}, 20 MW_{el}, with the steam data 470°C/80 bar. It is designed for wood fuels like demolition wood and forest residues. The corrosion on superheaters will primarily be studied as well as the impact on emissions. The goals are to

- decrease the corrosion rate by at least 50%,
- decrease fouling and decrease the dioxin emissions with at least 50% in a waste wood/biomass fired CHP-boiler.

Figure 29: The Jordbro power plant (photo: Vattenfall)

From 2010 until March 2011 installation of the ChlorOut injection system was carried out. The next phase started in April 2011, namely start-up and optimisation to achieve minimum corrosion rate and maximum NOx and CO reduction. This crucial work will continue throughout 2012. Vattenfall BU Heat has performed installation of the hardware associated with the ChlorOut system in the Jordbro CHP plant. The installation work includes planning, engineering, manufacture, assembly and commissioning of the equipment. The equipment comprises a 40 m^3

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storage tank, a pump station with associated installation and commissioning, pipes to boiler house top, an intermediate storage tank (~2 m^3) in boiler house, dosing pumps, lances etc. Furthermore, BU Heat has been involved in the planning, performance and evaluation of the ChlorOut short term testing managed by VRD. The installation work has been successful, although there are still some open tasks regarding the large storage tank and the pumping station that will be solved during 2012.

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 contributors to the Norwegian NOx emissions, higher production of district heating is mentioned as one of the contributors to the increased emissions of NOx from 2009 to 2010, together with increased activity in the manufacturing industries and higher production of gas power (Ref. SSB).

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

This emphasize that emissions from waste and biomass combustion are a continuous concern and continuous efforts with respect to emission minimisation are needed in order to ensure that the planned/future increase in bioenergy use is environmentally benign. Stricter regulations are expected in the future for WtE (waste-to-energy) and BtE (biomass-to-energy) plants and also for 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 emission will be developed. The objectives of this WP are:

Main: Develop new recipes for low-emission plants
- Develop numerical tools and methods required to study concept improvements
- Get increased insight in mechanisms for NOx formation and reduction
- Define state-of-the-art for NOx reduction measures in WtE and BtE plants
- Map the emissions for one specific plant by carrying out extensive measurements
- Map the emissions for BtE plants

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

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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 and the mapping campaign was carefully planned and prepared in 2011. It will be carried out in 2012 at Energos´ WtE-plant in Sarpsborg. State-of-the-art measurement diagnostic equipment (FTIR, GC – see Figure 30) will be utilised. A similar measurement campaign is planned at the Akershus Energi BtE-plant in 2012. Such extensive emission measurements like this have hardly carried out earlier at Norwegian plants.

Figure 30: FTIR gas sampling and conditioning unit (photo: Sascha Njaa, SINTEF)

The mapping will also 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 will be carried out to verify the emission level if a new concept or improved conditions are included at the plant.

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

Modelling of NOx precursors release is an important a topic in WP3.4. CHEMKIN calculations and characterisation studies (WP1.3 and WP2.1) will support the CFD modelling and serve as basis for verification of the CFD calculations. As CFD is a useful tool to study mixing behaviour, combustion and emissions in furnaces, CFD, including detailed chemical kinetics, will be used in order to develop new concepts or to optimise existing processes, combined with measurements for existing plants or combustion units (e.g. wood stoves).

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In 2011 a literature survey on NOx reduction measures in WtE and BtE plants was carried out. The main conclusions were:

- For air staging, studies of various biomass fuels in have demonstrated significant reductions in NO_x emissions (up to 85% depending on the technology). Air staging applied to municipal solid waste incineration; however, does not seem to have a positive effect on the level of NO_x emissions.

  Reburning is an in-furnace NO control technique which uses fuel to reduce nitric oxide. Some fuel is injected above the main heat release zone, creating a fuel-rich zone known as the reburning zone. Subsequently, overfire air is added to complete combustion. With advanced reburning, maximum NO_x reductions ranging from 90 to 96% have been achieved using various biomasses as reburn fuels.

- Flue gas recirculation has primarily been applied to the combustion of natural gas, oil, or coal for NO_x reduction purposes, but can also be applied for biomass and waste combustion with very positive results when it comes to NOx reduction.

- SNCR (Selective Non-Catalytic Reduction) is a widespread process for NO_x reduction in power plants. Application of SNCR in a municipal solid waste incinerator has demonstrated a 70% reduction of NO_x. An improved efficiency of the SNCR system was demonstrated with a new process involving internal recirculation of flue gas, leading to reported NO_x values of 80 mg/Nm^3 at 11% O_2 level.

- SCR (Selective Catalytic Reduction) is the most widely used secondary NO_x control measure for fossil fuel combustion. At the WtE plant in Brescia, Italy, an SCR 'high-dust' system has been installed with NO_x emissions in the range 60-70 mg/Nm^3.

In 2011 a work has also been carried out by the industrial CenBio partner Energos AS. This work is connected to NOx reduction by primary measures, and they have studied reduced kinetic mechanisms for syngas (mainly CO, H_2, and some CH_4). The main purpose of this work is to perform CFD simulations using COMSOL and optimize the syngas combustion process including reduced kinetic mechanisms both for syngas oxidation and thermal NOx chemistry. The work is linked to WP2.1.

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SP4 Sustainability analysis

Sustainable bioenergy value chains

This sub-project will document the sustainability of bioenergy value chains, and is based on information obtained from all the other CenBio work packages. The work is divided into three parts.

The first deals with extended life-cycle assessments (LCA), taking into account factors such as the profile of GHG emissions over time, albedo and indirect GHG impacts. These have only seldom been taken into account in traditional LCAs. For instance, the point in time of capture and release of climate gases in forest used for energy purposes is crucial for the climate impact. In an even-aged Norwegian forest, CO_2 capture is at its highest at around 20-80 years of age, while carbon release is highly dependent on the end use and the corresponding life-time of the woody biomass.

When woody biomass is harvested, some nutrients are removed from the forest soil. This is studied in the second part of this sub-project. When only the trunks are harvested, we know that for many years nutrient loss is low or insignificant. However, we know much less about nutrient loss when whole trees (trunk, top and branches) are removed. Our studies tell us that harvesting whole trees during forest thinning leads to lower production in the remainder of the stand. The reduction in growth in spruce stands 25 years after thinning and whole tree removal is significant, and may be as much as 10%, compared with only trunk removal. In pine stands, the loss of productivity is lower.

In the last part of this sub-project, we analyse how the international market for forest products (timber, wood chips, and industry products), energy prices and policy measures influence Norwegian forestry and forest industries, including the production and consumption of timber-based bioenergy. Timber and bioenergy are international commodities, and the price depends on supply and demand as well as policy measures, particularly in large markets such as the EU. Norway possesses large forested areas, but the EU's carbon price and energy policy is likely to have serious impacts on timber prices and the Norwegian forestry sector. Our project is also developing analytical models for estimating such impacts and the consequences of choosing forest management and forest harvesting strategies.

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

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WP4.1 Extended Life Cycle Assessment

In the spring of 2011 CenBio researchers published an article in the international journal Global Change Biology Bioenergy that proposed a new method to account for CO_2 emissions from biomass combustion in bioenergy systems.

CO_2 emissions resulting from bioenergy production have traditionally been excluded from most emission inventories and environmental impact studies because bioenergy is carbon- and climate-neutral as long as CO_2 emissions from biofuel combustion are sequestered by growing biomass. Its climate impact has not therefore been considered.

Cherubini and co-authors propose that CO_2 emissions from biomass combustion for bioenergy should no longer be excluded from Life Cycle Assessment studies or be assumed to have the same global warming potential as anthropogenic CO_2 emissions. Carbon dioxide is emitted when biomass is burnt and the sequestration in the new vegetation can be spread for up to several decades in the case of slow-growing biomass, like forests.

The authors believe that the global warming potential of CO_2 emissions from bioenergy production depends on the interactions with the full carbon cycle and its sinks, the oceans and the terrestrial biosphere, which work on different time scales. Most significant is the formulation of mathematical functions (Impulse Response Functions) to predict atmospheric decay of CO_2 emissions from biomass combustion and the adoption of an index to estimate the contribution of those emissions to global warming.

According to Dr. Francesco Cherubini, Researcher at the Norwegian University of Science and Technology (NTNU), "This work reduces the inaccuracy of CO_2 accounting in environmental impact studies, and is a first step towards the development of an accurate and standardized procedure for quantifying the effective climate impact of CO_2 emissions from biomass combustion."

These methodological developments have now caught the attention of many researchers internationally. However, to what extent it may have repercussions on national GHG accounting schemes remains to be seen.

The Laudise Medal was awarded to a CenBio researcher, namely professor Anders Hammer Strømman (NTNU), in the beginning of June 2011. The Laudise Medal is awarded every second year by The International Society for Industrial Ecology (ISIE) to a researcher who has made an excellent contribution to research in industrial ecology in the early part of his or her career.

The award was handed out by Professor Marian Chertow from Yale University during the ISIEs conference at UC Berkley. The jury emphasized in their statement that Strømman has given a substantial contribution to improve the methodology for life cycle analysis. They also emphasized his work within environmental assessment of bioenergy and global production systems.

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WP4.2 Ecosystem management

Long-term studies show an effect of slash removal

In WP4.2, we are looking at the effects of increased biomass removal for bioenergy on the forest ecosystem, including tree growth during the next rotation. The 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. To test this, we are using the results from long-term field experiments. Eight field trials were established in eastern Norway in 1972-1977, four in Norway spruce stands and four in Scots pine stands. There were two treatments: conventional stem-only thinning (CH) and whole-tree thinning (WTH).

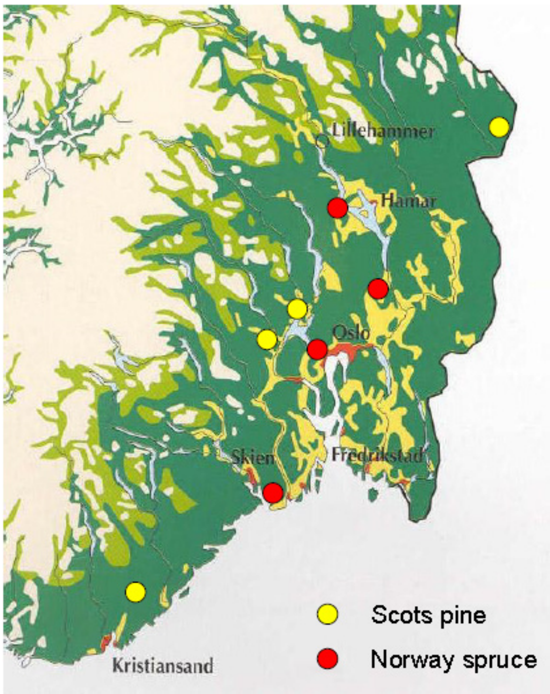

Figure 31: Location of the field trials.

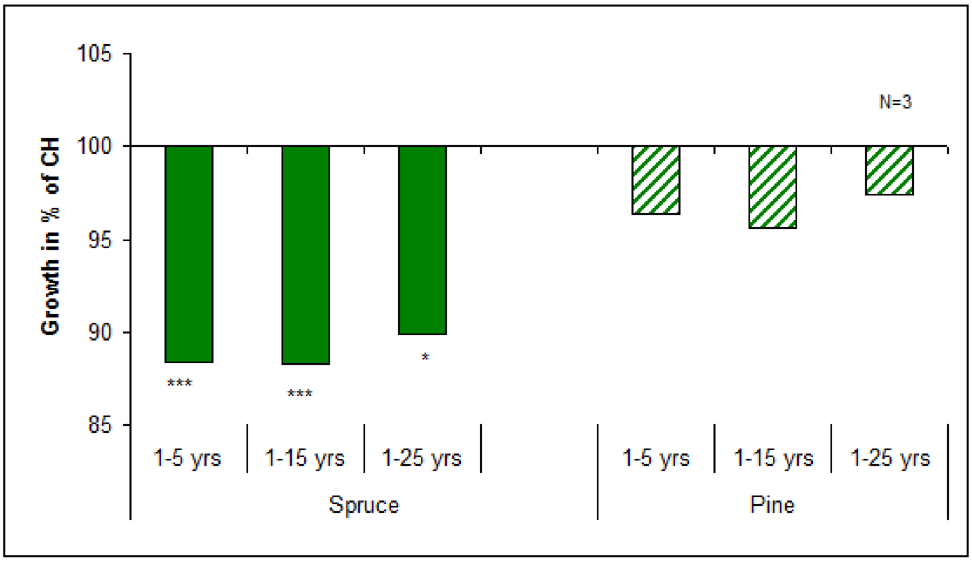

Figure 32: Growth after WTH, in percent of control plots (CH).

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The results show that:

- WTH did decrease forest growth; but only significantly so for spruce (by about 10 %)
- In plots with growth reduction, production dropped straight after thinning
- The effect is still there after 25 years
- A stronger growth decrease took place in spruce than in pine stands

Our results agree well with results from similar Swedish and Finnish field trials. These results are being prepared for publication in high-ranking international peer reviewed journals with funding from CenBio.

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

Increased bioenergy demand may strongly impact international trade and prices of wood fiber

The price of wood fibre for bioenergy production in Norway depends heavily on the national and international competition for wood and wood products. One goal of WP4.3 is to analyse the international supply and demand for forest biomass, with particular reference to the impacts of increased energy prices.

In that context WP4.3 participated heavily in the European Forest Sector Outlook Study II (EFSOS II) lead by FAO and the UN Economic Commission for Europe, which every 10 year assemble the best research groups in Europe for such analyses. WP4.3's contribution was mainly on analysing trade data (UN COMTRADE) and applying the bio-economic forest sector model EFI-GTM.

Regarding trade, we found that while the share of wood trade in total wood and wood based product imports has remained relatively stable (around half), the importance of wood chips and wood based residues has risen significantly in the last few years (Figure 33). Despite the drop in all forest products trade caused by the global economic recession, the volumes of wood chips and especially wood residues trade increased, (except for a modest decline in 2009). The main reason seems to be the growth in the trade of pellets. Wood chips trade was growing partly due to the increase of the Russian logs export tariff.

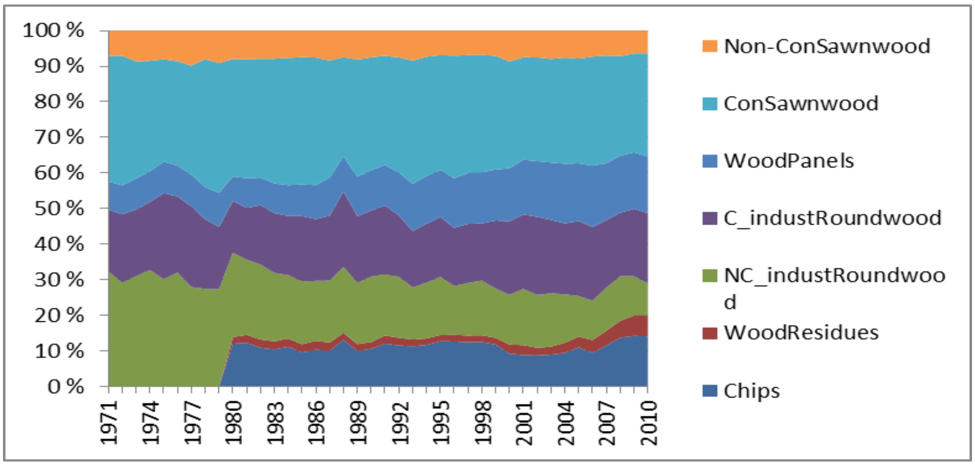

Figure 33: Share of wood and wood products imports in the global trade (calculated on the m^3 basis. Source: UN COMTRADE)

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It is expected that trade of chips and especially wood residues and pellets will be growing because of the EU RES 2020 target. Analyses done (with among other the EFI-GTM model) show that in order to fulfil the 20% RES target, the volume of wood biomass used for energy will double over the 2010-2030 period, while use of wood for forest products will increase only marginally (Figure 34).

The highest growth is expected in the category of Wood fired CHP mills, which are going to use logging residues and wood pellets.

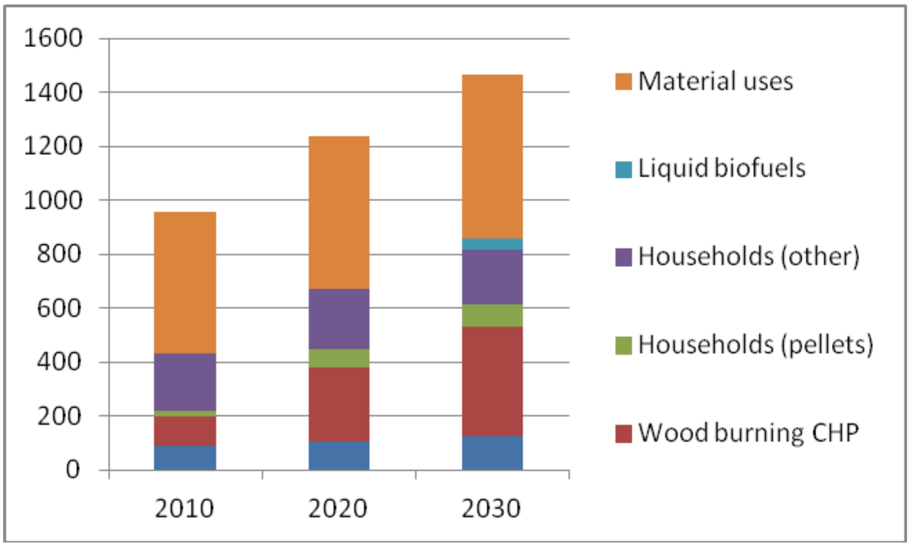

Figure 34: Use of wood in EFSOS "Promoting wood energy" - scenario, 2010-2030.

Depending on prices even pulpwood can be used for energy if fossil fuel prices continue growing complemented by increasing CO_2 prices. Use of wood biomass for energy depends on the price paid at Energy mill gate, and some preliminary results from our analyses are shown in Figure 35.

In the long run (year 2030) wood resources utilization is estimated to be close to the sustainable maximum supply, and it will be difficult to increase forest fellings for energy purposes. However, with increasing energy wood prices, competitive use of wood (use of wood for energy instead of use of wood for wood products) and additional imports will become major additional resources.

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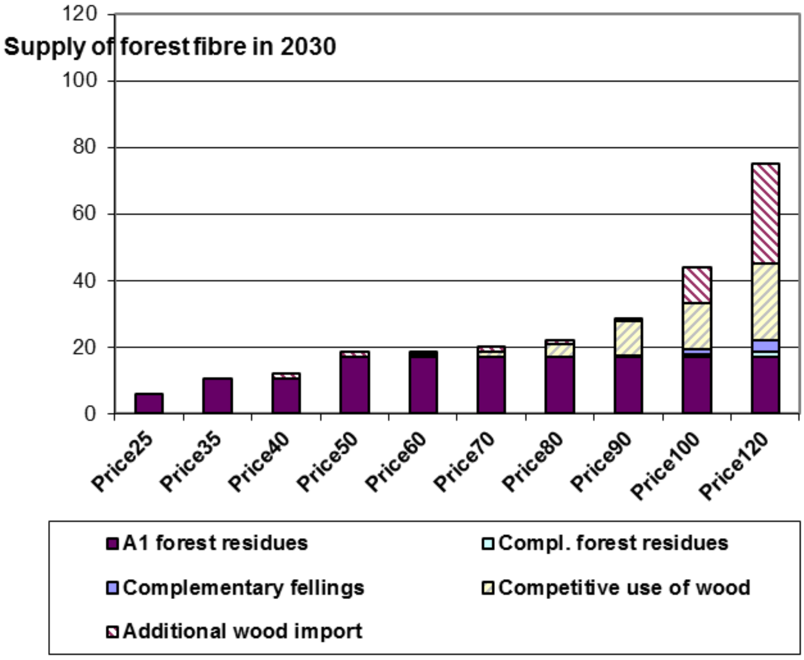

Figure 35: Total supply of wood biomass (Mtoe) for energy use in EU from different sources in 2030 as a function of wood chip price. X-axis: Wood chips price, €/m^3 at mill gate. 1 m^3 wood (oven-dry) = 0.208 toe. Source: Moiseyev et al., 2011.

The latter will have a significant impact on the competitiveness of the European forest sector. Currently European forest sector (without Russia) is a net wood products exporter (see Figure 36) and minor wood importer with the positive net export of wood in round wood equivalent (RWE). Our analyses to EFSOS II show (Figure 36) that under the reference scenario (EU 2020 RES policy is not enforced) Europe will increase wood products net exports while reducing wood imports. Under the "wood energy" scenario wood products exports will be reduced (relative to the reference scenario), while wood imports will increase substantially.

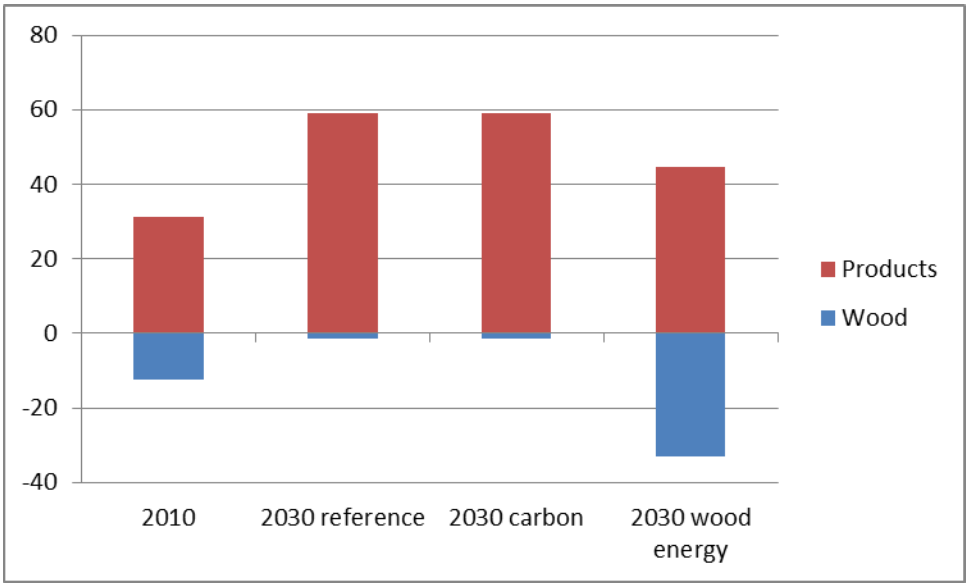

Figure 36: Europe net trade in three scenarios, 2010-2030. Millions m^3, RWE. Source: EFSOS II.

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The work has contributed to the European Forest Sector Outlook Study II and parts of it are published as a peer-reviewed article in the Journal of Forest Economics. Future work will focus at a more detailed investigation of the economic aspects of use of woody biomass in the energy sector, including competition between wood and coal and other types of energy based on fossil fuels.

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SP5 Knowledge Transfer and Innovation

Technology and bioscience as a team

If Norway's ambition for strong growth in bioenergy is to be more than fine words, the country will need to train young people with a broader professional horizon than is usual in the rest of the energy industry. For the "bio" section of the energy sector we need candidates with a broad understanding of the available resources, logistics, economics and technology involved. We have integrated these needs into the training activities of CenBio.

In the bioenergy sector, production units are far smaller than they are in the oil, hydropower and distribution segments of the energy sector. In practice this requires professionals in the bioenergy sector to possess expertise that covers a larger share of the value chains, compared to colleagues in the big energy sectors.

In CenBio we have accepted this challenge by establishing a pilot project in which the Norwegian University of Science and Technology (NTNU) and the Norwegian University of Life Sciences (UMB), jointly offer distance education in the field of bioenergy.

Our fourth- and fifth-year courses bring together young people who would previously have been specialists in either thermodynamics or forest management. Now, MSc students in Trondheim (the technical university) learn about energy conversion, while in Ås (the life sciences university) they learn about the resources for bioenergy.

This programme is unique, and from an educational perspective there have been many challenges. The learning curve has been steep for both students and teaching staff, but the experience has been overwhelmingly positive.

Recruitment to the bio-energy sector is very much about creating motivation, and to this end, we believe that the cooperation between educational institutions in Trondheim and Ås is a good - and very important - step.

Anders Hammer Strømman
Leader of Knowledge transfer and innovation
(photo: NTNU)

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WP5.1 Bio-Energy Graduate School

The Bio-Energy Graduate School strives for promoting studies in bioenergy. The successful master course in bioenergy runs as a collaborative course between UMB & NTNU and is now established as a regular course at the two universities, strongly increasing the number of master candidates with knowledge in bioenergy systems. This is important for the recruitment of candidates both to industry, public sector and research institutions.

The Bio-Energy Graduate School also makes sure of disseminating information to more than 30 PhD candidates affiliated with CenBio. This is information on potential courses, seminars, industry cases etc. The Graduate School has also arranged two gatherings – one workshop for PhD candidates during the CenBio days in January 2011 and one excursion in collaboration with the above mentioned master course.

The Bio-Energy Graduate School is also actively involved in establishing a PhD level course on renewable energy together with other FMEs and Centre for renewable energy.

WP5.2 Knowledge transfer and dissemination

Scientific publishing

Objective: Promote publishing all findings in international scientific journals

Open research CenBio results are being published in international scientific journals and presented at reputed international conferences. During 2011, CenBio researchers were active producing scientific articles. The 2011-target was to submit 10 papers. The result at the end of the year was 15 papers and 2 chapters in two books published, 1 paper accepted for publication and 4 submitted to journals. In addition, 5 papers were in progress per December 2011, and 21 more are scheduled to be produced in 2012.

The overall target for an 8 year period is to produce 75 journal papers. This means about 10 papers per year in average. So far, after 3 years in operation 25 papers have been published and 5 submitted or accepted. This means that we are now slightly behind schedule, not surprisingly because of a slow start in 2009 as much work and energy had to put into establishing the centre. The successful acceptance of the papers we have in progress will ensure that we are well on track.

Thematic
All research partners are engaged in high quality scientific publishing. It is worth noticing that many CenBio papers deal with sustainability. For example, in an article in the international journal Global Change Biology a new method to account CO_2 emissions from biomass combustion in bioenergy systems was proposed. This method reduces the inaccuracy of CO_2 accounting in environmental impact studies, and is a first step towards the development of an accurate and standardized procedure for quantifying the effective climate impact of CO_2 emissions from biomass combustion. These methodological developments have now caught the attention of many researchers internationally.

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International conferences
CenBio researchers gave presentations in several international conferences in 2011. Some examples:

- Transatlantic Science Week, USA. About R&D-collaboration between North America and Norway, arranged by the Research Council of Norway and The Norwegian Embassy. All FMEs were presented. Discussions with CenBio associate partners University of California at Berkeley and Stanford University.
- Biogas Day, Norway. About recent findings within anaerobic treatment. Arranged by the CenBio industry partner Cambi AS in collaboration with UMB and Bioforsk. Presentations by Norwegian, Swedish and Danish researchers.
- 4th World Forest Engineering, South Africa. A strong focus on bioenergy. This international conference is held every 4 years and gathers all significant research environments working with forest engineering.
- COST FP0902, Austria. About Development and harmonisation of new operational research and assessment procedures for sustainable forest biomass supply.

Industry involvement
Objective: Transfer knowledge from research to business

CenBioDays
Most of the industry partners participated CenBio Days, a two-day event taking place in Trondheim in January 2011. They gave presentations in addition to the scientific talks and were active in the thematic discussions. CenBio Days is a meeting place for all CenBio partners, plus our international scientific advisory team. Here discussions across the working groups and between academia and business take place. Also, all CenBio people, industry and research, get the chance to mingle and get better acquainted with each other.

Example: Skogeierforbundet
When producing bioheat from forest biomass, the close link between feedstock quality and conversion technology is crucial for the efficiency. Feedstock producers want to benefit from new knowledge about conversion technologies and smart ways to produce high quality feedstock. Several local units of Skogeierforbundet participated in three dedicated workshops in 2011 arranged by CenBio, discussing how to produce wood chips of good quality. Also, the management group of Skogeierforbundet had discussions with CenBio staff on how to handle the national and international sustainability debate.

Popular publishing
Objective: Be a proactive player in public discussions

23 popular articles and press news were published in 2011, thereof 7 in the national research web-site *forskning.no*. Some of them were produced by the CenBio industry partners. See Table 19.

Example: 14 TWh is possible, but is subject to profitability
The national target to double our bioenergy consumption from 2008 to 2020 with national biomass, most of it from forest resources, is possible to obtain (SKOGeieren 5-2001). The availability of the biomass resources has been mapped and there is enough to harvest. However, the actual harvest level depends heavily on profitability for both the forest owners and the energy producers.

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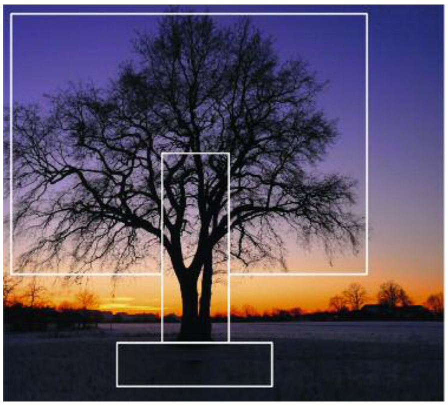

Figure 37: The biomass of a tree can be divided into three parts, 25% in branches and top, 50% in stem wood and 25% in roots. The latter part is not recommended for harvest. (photo: Inge Jahren, Tidskriftet Skog)

WP5.3 Innovation Management

The target is 25 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 innovations, and innovation is also one of the success criteria for the Research Council´s mid-term evaluation of the FMEs in 2012-2013. The activities in this work package ensure that innovation is an integrated part of CenBio.

In the CenBio innovation work three primary mechanisms are emphasized;

1. Arenas for communication
2. Will to innovate
3. Systems and assistance

Several specific activities and actions are pointed out in the CenBio Innovation plan that is regularly updated.

It was important to establish a common understanding of innovation and how to implement the innovation activity in CenBio, and this has been discussed in the two innovation workshops that were arranged in 2010 and 2011. A CenBio definition of innovation has been approved by CenBio partners and the Research Council of Norway, and innovation is included as a guiding star in the annual work plans. The "List of innovations" includes more than 30 potential innovations identified per today, and we are working systematically to develop these. Three innovations are so far completed/fully implemented:

- Afterburner for woodstoves developed to ensure that Norwegian environmental requirements are fulfilled
- New test method for wood stoves. It is time-saving (25-50%) compared to existing methods and also cost-saving
- Albedo and forests - New knowledge developed on the importance of Albedo for climate and forest management as well as policy development

CenBio has introduced the “Bioenergy Innovation Award” (BIA), a national innovation award within stationary bioenergy. This award was established to stimulate and reward knowledge-based

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innovation and entrepreneurship. The Bioenergy Innovation Award 2011 was announced nationally and was awarded 18 January 2012 during the CenBio days to Cambi AS, one of the CenBio partners for their innovative biogas production process for biomass from waste and sewerage that is implemented in many plants world-wide.

Figure 38: The CenBio partner Cambi wins the 2011 Bioenergy Innovation Award. From left Odd Jarle Skjelhaugen, CenBio/UMB, Lars Sørum, CenBio/SINTEF, Per Lillebø, CEO Cambi, Pål Jahre Nilsen, Research director at Cambi and Ruth Haug, prorector for research at UMB (photo: Kai Tilley)

FME CenSes has been actively involved in the CenBio Innovation workshops, a cooperation that will be increased in 2012.

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INTERNATIONAL COOPERATION

International organisations

In Table 6, various IEA Bioenergy tasks with involvement of CenBio staff are listed.

Table 6: Participation in IEA Bioenergy activities

IEA Bioenergy Task No	Task title	Task member WP No	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	Judit Sandquist
Task 36	Integrating Energy Recovery into Solid Waste Management Systems	02 SINTEF-ER WP3.2	Michaël Becidan
Task 37	Energy from biogas and landfill gas	04 BIOFORSK WP2.4	Espen Govasmark
Task 38	Greenhouse gas balances of biomass and bioenergy systems	01 UMB+03 NTNU	Anders Strømman
Task 40	Sustainable International Bioenergy Trade - Securing Supply and Demand	01 UMB WP4.3	Birger Solberg Erik Trømborg
Task 43	Biomass feedstocks for energy markets	05 NFLI WP1.1	Simen Gjølsjø

SINTEF Energy Research is also involved in several EU strategic initiatives:

- The EERA (European Energy Research Alliance) Network both on stationary bioenergy and biofuels
- The Renewable Heat and Cooling (RHC) Technology Platform (TP)

SINTEF Energy Research participates actively in PREWIN European Network (see WP3.2)

NFLI is well represented in COST FP0902: Development and harmonisation of new operational research and assessment procedures for sustainable forest biomass supply.

NFLI participates in the Nordic-Baltic network Operations Systems Centre of Advanced Research (OSCAR) supported by the Nordic Council of Ministers dealing with Forest biomass supply.

NFLI is part of a Nordic Energy Fund project within the frame of 'Sustainable Energy Systems 2050'. The project, called Wood based energy systems from Nordic forests (ENERWOODS), is coordinated by Denmark and includes numerous institutes in Sweden and Finland.

NFLI participates in a Nordic network on forest soil carbon, funded by NordForsk. Effects of forest management, including harvesting for bioenergy, on soil organic carbon stock and C sequestration are among the topics. CenBio contributes to this network.

NFLI also participates in a Centre of Advanced Research on Ecosystem Services with partners from all the Nordic countries, Latvia and Lithuania, which includes work on the effects of biomass harvesting for bioenergy on forest ecosystems. CenBio contributes to this centre.

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International conferences

CenBio has been presented at several international conferences in 2011. Details are listed in Table 16.

International institutions

The institutions listed below were involved during the application phase of CenBio in 2008. During the third year of operation there has been some contact on individual basis with personnel from some of these institutions.

- Stanford University (USA)
- US Forest Service
- University of Minnesota (USA)
- Finnish Forest Research Institute
- Chalmers University of Technology (S)
- Abo Akademi University (SF)
- Technical University of Denmark
- University of Copenhagen (DK)
- Vienna University of Technology (A)
- Technical University Bergakademie Freiberg (D)

Lars Sørum visited University of California Berkley and Stanford University, 25-28 October 2011 to follow up LoIs to CenBio. As a result a professor from Stanford is expected to visit Trondheim in June 2012.

The fruitful cooperation with Professor Michael J. Antal, Jr. from University of Hawaii has continued in 2011. The focus research area has been pyrolysis.

Some other examples of high-level international collaboration within the forest sector during 2011:

- European Forest institute, Finland.
  Topics: Forest sector analysis. International forest fibre supply
  Type of collaboration: Data input. Analyses. Article writing/publishing.

- Finnish Forest Research Institute (METLA). Helsinki.
  Topics: Forest sector modelling. International demand/supply of forest products.
  Type of collaboration: Data input. Analyses. Article writing/publishing.

- Swedish University of Agricultural Sciences (SLU), Sweden.
  Topics: Anaerobic digestion.
  Type of collaboration: ass. Prof. Anna Schnürer, part-time position at UMB.

- Aalborg University, Denmark.
  Topics: Anaerobic digestion.
  Type of collaboration: ass. Prof. Jens Bo Holm-Nielsen, part-time position at UMB.

- University of Minnesota - Department of Forest Resources.
  Topics: Timber supply. Costs of bioenergy production based on forest resources.

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Type of collaboration: Data input. Comparative analyses. Article writing/publishing. Planned exchange of PhD and Post.Doc.

RECRUITMENT

The research within CenBio is mainly performed by permanent employees with the research institutes and the universities. In some cases postdoctoral researchers have been recruited to perform CenBio research. A list of such researchers is shown in Table 9.

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COMMUNICATION AND DISSEMINATION

Website

The first version of the CenBio website was established and published in June 2009. Figure 39 show the front page as of 2011.

Figure 39: CenBio website

The website is regularly updated, especially with new public deliverables.

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 Table 20 shows the deliverables that were finalised in 2011.

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. The number for this report illustrates the numbering system: D0.1.4_3 where 0.1 refers to WP0.1, 4 is selected as the unique number for annual reports while the _3 means the third in a series; i.e. annual report for the third year of operation.

One of the overall targets for CenBio is to deliver 150 international publications, of which 75 in reputed refereed journals. Figure 40 shows the current status.

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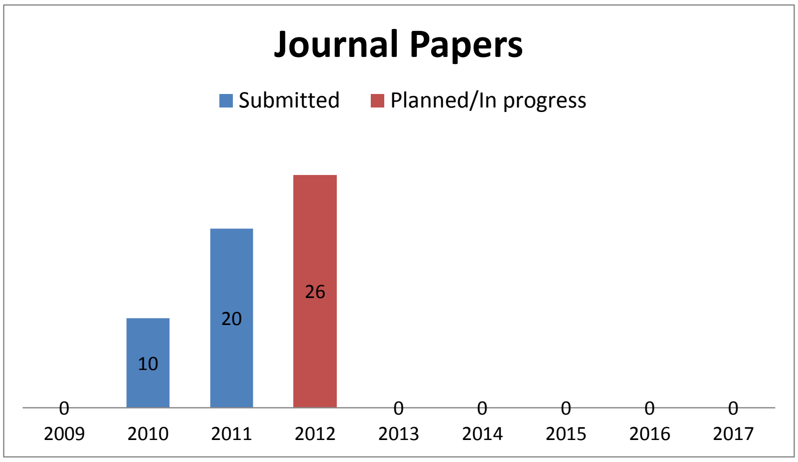

Figure 40: Status of peer-reviewed articles as per 31 December 2011

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APPENDICES

Personnel

Key Researchers

Table 7: List of key researchers

Name	Sex	Affiliation	Topic/Research area	Funding	Duration
Odd Jarle Skjelhaugen	M	01 UMB	Coordination	CenBio	
Tron Eid	M	01 UMB	Feedstock supply	CenBio	
Øivind Løken	M	01 UMB	Feedstock supply	CenBio	
Olav Høibø	M	01 UMB	Biomass and residue characteristics	CenBio	
Birger Solberg	M	01 UMB	Sustainability analysis	CenBio	
Vincent Eijsink	M	01 UMB	Pretreatment & biogas	CenBio	
Svein Jarle Horn	M	01 UMB	Pretreatment & biogas	CenBio	
Alexander Moiseyev	M	01 UMB	Sustainability analysis	CenBio	
Lars Sørum	M	02 SINTEF-ER	Coordination	CenBio	
Einar Jordanger	M	02 SINTEF-ER	Coordination	CenBio	
Øyvind Skreiberg	M	02 SINTEF-ER	Conversion technologies	CenBio	
Michaël Becidan	M	02 SINTEF-ER	District heat	CenBio	
Edvard Karlsvik	M	02 SINTEF-ER	Wood- and pellet stoves	CenBio	
Roger Khalil	M	02 SINTEF-ER	Biomass and residue characteristics	CenBio	
Judit Sandquist	F	02 SINTEF-ER	Biomass and residue characteristics	CenBio	
Franziska Goile	F	02 SINTEF-ER	Conversion technologies	CenBio	
Bjarne Malvik	M	02 SINTEF-ER	Conversion technologies	CenBio	
Berta Matas Güell	F	02 SINTEF-ER	Conversion technologies	CenBio	
Inge Saanum	M	02 SINTEF-ER	Conversion technologies	CenBio	
Sigurd Sannan	M	02 SINTEF-ER	Conversion technologies	CenBio	
Liang Wang	M	02 SINTEF-ER	Conversion technologies	CenBio	
Mette Bugge	F	02 SINTEF-ER	Innovation Management	CenBio	
Anders Strømman	M	03 NTNU	Knowledge Transfer and Innovation	CenBio	
Ottar Michelsen	M	03 NTNU	Bio-Energy Graduate School	CenBio	
Francesco Cherubini	M	03 NTNU	Life cycle assessment	CenBio	
Trond K. Haraldsen	M	04 BIOFORSK	Residues upgrading and use	CenBio	
Roald Sørheim	M	04 BIOFORSK	Anaerobic Digestion	CenBio	
Tormod Briseid	M	04 BIOFORSK	Anaerobic Digestion	CenBio	
Roar Linjordet	M	04 BIOFORSK	Anaerobic Digestion	CenBio	
Helmer Belbo	M	04 BIOFORSK	Biomass supply logistics	CenBio	
Bruce Talbot	M	05 NFLI	Logistics	CenBio	
Anders Eid Hohle	M	05 NFLI	Biomass supply and residue utilization	CenBio	
Simen Gjølsjø	M	05 NFLI	Biomass supply and residue utilization	CenBio	
Tore Filbakk	M	05 NFLI	Biomass characteristics	CenBio	
Rasmus Astrup	M	05 NFLI	Biomass supply and residue utilization	CenBio	
Aaron Smith	M	05 NFLI	Biomass supply and residue utilization	CenBio	
Nicholas Clarke	M	05 NFLI	Ecosystem management	CenBio	
Janka Dibdiakova	F	05 NFLI	Ecosystem management	CenBio	
Bjarte Arne Øye	M	06 SINTEF-MC	Residues upgrading and use	CenBio	
Åsa Astervik	M	07 VRD	Heat and power	CenBio	

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Visiting Researchers

Table 8: List of visiting researchers

Name	Sex	Affiliation	Topic/Research area	Funding	Duration
Ass.prof. Dennis Becker	M	U o Minnesota USA,	Policy for forest biomass to energy	U o Minnesota	One week
Prof Mike Kilgore	M	U o Minnesota USA	Policy for forest biomass to energy	U o Minnesota	One week
Prof Michael J. Antal, Jr.	M	U o Hawaii USA	Production of biocarbon	CenBio	One week

Postdoctoral researchers

Table 9: List of postdoctoral researchers

Name	Sex	Affiliation	Topic/Research area	Funding	Duration
Francesco Cherubini	M	03 NTNU	LCA bioenergy systems	CenBio	2009-10 2011-09
Marit Lie	F	01 UMB	Bio diversity forest and sustainability	UMB	2010 2012
Bjørge Westereng	M	01 UMB	Enzym processes	UMB	2010 2012
Zehra Zengin	F	01 UMB	Biogas	UMB	2010 2012

PhD students

A database on PhD students working on issues in relation to CenBio is established, see Table 10.

Table 10: List of PhD students, CenBio funded and associated

Name	Sex	Affiliation	Topic/Research area	Funding	Duration
Paulo Borges	M	01 UMB	Develop decision support systems for long-term analyses of biomass	CenBio WP1.1	2010-11 2013-11
Aron Smith	M	05 NFLI	Develop models and methods for quantification of birch biomass	CenBio WP1.1/ RCN	2010-08 2013-08
Dmitry Lysenko	M	03 NTNU	Combustion modelling	CenBio WP2.1	2010-03 2014-03
Dhruv Tapasvi	M	03 NTNU	Experimental studies on biomass torrefaction and gasification	CenBio WP2.3	2010-01 2013-01
Ehsan Houshfar	M	03 NTNU	Experimental studies on two-stage combustion of biomass	KRAV CenBio In-kind	2009-03 2012-02
Quang Vu Bach	M	03 NTNU	Thermal pre-treatment of biomass and biomass residues	CenBio WP2.5	2011-08 2014-08
Geoffrey Guest	M	03 NTNU	Hybrid life cycle analysis of solid bio-fuel systems	CenBio WP4.1	2009-08 2012-09
Ryan Bright	M	03 NTNU	LCA of Second Generation Biofuels		2008-09 2011-11
Shuling Chen Lillemo	F	01 UMB	Bioenergimarkeder	RCN	
Maria M. Estevez	F	01 UMB	Optimization of biogas production (From biomass to biogas project)	RCN	2009-12 2012-11
Kristian Fjørtoft	M	01 UMB	Biogas optimization in farm scale biogas plants	UMB	2009-08

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Name	Sex	Affiliation	Topic/Research area	Funding	Duration
Zarah Forsberg	F	01 UMB	Characterization and directed evolution of carbohydrate-binding modules (CBMs) for biomass conversion	RCN	2010-01 2013-12
Per-Ivar Hanedalen	M	01 UMB	Life cycle assessment of bio energy based on raw materials from agricultural systems	UMB	2009-09 2013-01
Dhandapani Kannan		03 NTNU	Study of Diesel Combustion and Emissions with Fischer-Tropsch (F-T) fuels and Bio fuels		2008-09 2011-09
Kavitha Pathmanathan	F	03 NTNU	High Temperature Filtration of biomass combustion and gasification processes		2007-06 2011-06
Hanne K. Sjølie	F	01 UMB	Economic analyses of use of forest and wood products in Norway to reduce the atmospheric concentration of greenhouse gases (GHG)	UMB	2007-11 2011-06
Geir Skjevrak	M	03 NTNU / Statoil	High Temperature Filtration of biomass combustion and gasification processes		
Silje Skår	F	01 UMB	Ecological modelling related to increased biomass removal in forests in Norway	RCN	2009-12 2013-12

Master degrees

The NTNU and UMB joint Master course *Bioenergy – resources, profitability and solutions* was given also in 2011.

Some details about the 2011 course:

Level: Master, 5 credit
Objective: After the course the students will be able to work with cross-cutting problems and planning processes linked to bioenergy plants.
Frequency: Annually, given for the second time autumn 2011.
Students: 55 from NTNU and UMB together
Activities: Two workshops, one at UMB and one at NTNU.
Six joint term papers: Same bioenergy case, but different feedstock, technologies and markets

Accounts

A detailed accounts report for 2011 was submitted to RCN in February 2012. The main financial figures are repeated in this annual report.

Budget

Table 11 shows the anticipated overall budget for CenBio over eight years, as presented in the AWP2012. The total costs are estimated at NOK 271,680 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 2011 was NOK 34,028 million while the estimate before final reporting for 2011 was NOK 32,840 million. The budgeted funding from RCN was NOK 15,000 million.

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Table 11: CenBio overall budget (source: CenBio Budget 2012)

		Actual	Actual	Actual	Budget	Plan				
mill. NOK	Total	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total	**271,680**	**27,738**	**38,594**	**39,291**	**34,722**	**33,828**	**33,828**	**33,828**	**33,828**	**-3,977**

Accounts 2011

Total costs reported from the partners in 2011 amounts to NOK 39,3 million, of which NOK 32,2 million from Research partners and NOK 7,1 million from Industry partners.
The funding from RCN amounts to 38% of the total costs.

Funding

Table 12: Funding from various sources 2011

Source	NOK million
The Research Council	15,000
Research partners	13,792
Industry partners	10,499
Public partners	0,000
Total	**39,291**

Costs

Table 13: Reported costs from various partners 2011

Type	NOK million
Research partners	32,217
Industry partners	7,074
Public partners	0,000
Equipment	0,000
Total	**39,291**

Publications

All types of publications produced within CenBio are listed in Table 20. Below some specific publications are listed in separate tables.

Journal Papers

Table 14: List of journal papers 2011

Title	Author(s)	Journal
An assessment of woody biomass in Norway: Total availability and harvest residue cost-supply curves	Rasmus Astrup, Tron Eid, Clara Antón-Fernández, Øivind Løken and Gunnhild Søgaard	Biomass and Bioenergy
Combustion Properties of Norwegian Biomass: Wood Chips and Forest Residues	Ehsan Houshfar, Judit Sandquist, Wilson Musinguzi, Roger A Khalil, Michaël Becidan, Øyvind Skreiberg, Franziska Goile, Terese Løvås and Lars Sørum	Applied Mechanics and Materials
Modelling natural drying efficiency in covered and uncovered piles of whole broadleaf trees for energy use	Tore Filbakk, Olav Høibø and Juha Nurmi	Biomass and Bioenergy

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Title	Author(s)	Journal
Modelling moisture content and dry matter loss during storage of logging residues for energy	Tore Filbakk, Olav Albert Høibø, Janka Dibdiakova, Juha Nurmi	Scandinavian Journal of Forest Research
Sintering behavior of agricultural residues ashes and effects of additives	Liang Wang, Michaël Becidan, Øyvind Skreiberg	Energy & Fuels
Experimental Investigation on Corrosion Abatement in Straw Combustion by Fuel Mixing	Roger A. Khalil, Ehsan Houshfar, Wilson Musinguzi, Michaël Becidan, Øyvind Skreiberg, Franziska Goile, Terese Løvås, Lars Sørum	Energy & Fuels
Effect of excess air ratio and temperature on NOx emission from grate combustion of biomass in the staged air combustion scenario	Ehsan Houshfar, Øyvind Skreiberg, Terese Løvås, Dušan Todorović, Lars Sørum	Energy & Fuels
The effect of kaolin on the combustion of demolition wood under well controlled conditions	Khalil R., Todorovic D., Skreiberg Ø., Becidan M., Backman R., Goile F., Skreiberg A. and Sørum L.	Waste Management and Research
The effect of peat ash addition on the combustion of demolition wood under well controlled conditions	Backman R., Khalil R., Todorovic D., Becidan M., Skreiberg Ø., Goile F., Skreiberg A. and Sørum L.	Fuel Processing Technology
Optimal biomass mixtures to reduce corrosion and deposition: a thermodynamic analysis	Michaël Becidan, Ehsan Houshfar, Roger A. Khalil, Øyvind Skreiberg, Terese Løvås, Lars Sørum	Energy & Fuels
Ash related behaviour in staged and non-staged combustion of biomass fuels and fuel mixtures	Becidan M., Todorovic D., Skreiberg Ø., Khalil R., Backman R., Goile F., Skreiberg A., Jovovic A. and Sørum L.	Biomass and Bioenergy
A critical review on additives to reduce potassium related operation problems in biomass combustion	Liang Wang, Johan E. Hustad, Øyvind Skreiberg, Geir Skjevrak, Morten G. Grønli.	Energy Procedia
Effects of additive on barley straw and husk ashes sintering characteristics	Liang Wang, Geir Skjevrak, Johan E. Hustad, Morten G. Grønli, Øyvind Skreiberg.	Energy Procedia
Is elevated pressure required to achieve the theoretical fixed-carbon yield of charcoal from biomass? 1. Round Robin results for three different corn cob materials	Liang Wang, Marta Trninic, Øyvind Skreiberg, Morten Gronli, Roland Considine and Michael Jerry Antal, Jr.	Energy & Fuels
Kinetics of corncob pyrolysis	Liang Wang, Geir Skjevrak, Johan E. Hustad, Øyvind Skreiberg	Energy & Fuels
Biogas production and saccharification of Salix pretreated at different steam explosion conditions	Horn SJ, Estevez MM, Nielsen HK, Linjordet R, Eijsink VG	Bioresource Technology
Torrefaction of Norwegian spruce and birch – An experimental study using macro-TGA	Dhruv Tapasvi, Roger A. Khalil, Øyvind Skreiberg, Khanh-Quang Tran, Morten G. Grønli.	Energy & Fuels
Chemicals from lignocellulosic biomass: opportunities, perspectives, and potential of biorefinery systems	Cherubini F, Strømman AH	Biofuels, bioproducts and biorefining
Climate impact of CO2 emissions from bioenergy: effect of management practices of boreal forests	Cherubini F, Strømman AH, Hertwich E	Ecological modelling
Impact assessment of biodiversity and carbon pools from land use and land use changes in LCA, exemplified with forestry operations in Norway	Michelsen O, Cherubini F, Strømman AH	Journal of Industrial Ecology
Material, energy and environmental performance of technological and social systems under a Life Cycle Assessment perspective.	Ulgiati S, Ascione M, Bargigli S, Cherubini F, Franzese P, Raugei M, Viglia S, Zucaro A.	Ecological modelling

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Title	Author(s)	Journal
Influence of rotation and anthropogenic storage periods on the climate impact of CO2 emissions from bioenergy	Guest G, Cherubini F, Strømman AH	Global Change Biology Bioenergy
GHG balances of bioenergy systems – Overview of key steps in the production chain and methodological concerns,	Cherubini F	Renewable Energy
The biorefinery concept: using biomass instead of oil for producing energy and chemicals	Cherubini F	Energy Conversion and Management
LCA of a biorefinery concept producing bioethanol, bioenergy and chemicals from switchgrass	Cherubini F, Jungmeier G	International Journal of Life Cycle Assessment
Impacts of EU RES policy on wood fibre supply and European forest industries	Solberg, B.	Journal of Forest Economics

Published Conference Papers (including extended abstracts and posters)

Table 15: List of conference papers 2011

Title	Author(s)	Conference
Using Network Analysis in configuring appropriate biomass supply systems	Bruce Talbot; Kjell Suadicani; Nils Egil Søvde	4th Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change. 5-7 April 2011, Stellenbosch University, South Africa
Using network analysis in configuring appropriate biomass supply systems.	Talbot, B., Søvde, N.E. & Suadicani, K.	4th World Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change , White River, South Africa, 5-7 April 2011. ISBN: 978-0-7972-1284-8.
Energy consumption and emissions in selected biomass supply chains	Hohle, A.	
Energy consumption by energy wood supply	Hohle, A	COST FP0902: Development and harmonisation of new operational research and assessment procedures for sustainable forest biomass supply *in cooperation with* International Symposium on Forestry Mechanisation (FORMEC) in Graz, Austria.
A simulation approach to determine the potential efficiency in multi-tree felling and processing	Belbo, H	
The drying of wood chips with surplus heat from two hydroelectric plants in Norway	Nordhagen, E	
Quality requirements for wood ash as K component in recycled NPK fertilizers (Proceedings)	Trond Knapp Haraldsen; Eva Martina Brod; Tore Krogstad	Ash Utilisation 2012; Stockholm, Sweden, January 2012
Efficiency of organic NPK fertilizers combining N-rich organic wastes and bottom wood ash	Trond Knapp Haraldsen; Tore Krogstad	NJF Seminar 443; Falköping, Sweden, November 2011
Wood ash as raw material for Portland cement	Bjarte Øye	Ash Utilisation 2012; Stockholm, Sweden, January 2012
Turbulent bluff body flows modeling using OpenFOAM technology	Dmitry A. Lysenko; Ivar S. Ertesvåg; Kjell Erik Rian	
Testing of OpenFOAM CFD code for plane turbulent bluff body flows within conventional URANS approach	Dmitry A. Lysenko; Ivar S. Ertesvåg; Kjell Erik Rian	8th International Conference on CFD in Oil & Gas, Metallurgical and Process Industries SINTEF/NTNU; Trondheim, Norway, June 2011

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Conference Presentations

Table 16: List of conference presentations 2011

Title	Author(s)	Conference
Using Network Analysis in configuring appropriate biomass supply systems	Bruce Talbot; Kjell Suadicani; Nils Egil Søvde	4th Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change. 5-7 April 2011, Stellenbosch University, South Africa
Economic feasibility of road transport of forest fuels		
Quality requirements for wood ash as K component in recycled NPK fertilizers	Trond Knapp Haraldsen; Eva Martina Brod; Tore Krogstad	Ash Utilisation 2012; Stockholm, Sweden, January 2012
Efficiency of organic NPK fertilizers combining N-rich organic wastes and bottom wood ash	Trond Knapp Haraldsen; Tore Krogstad	NJF Seminar 443; Falköping, Sweden, November 2011
Askerelatert forskning innen CenBio Foreløpige resultater	Trond Knapp Haraldsen	RCN (askeseminar)
Wood ash as raw material for Portland cement	Bjarte Øye	Ash Utilisation 2012; Stockholm, Sweden, January 2012
Varmeoverføring fra Granit Octo 50	Inge Saanum	CenBio internal
R1 – efficiency formula for WtE	Michaël Becidan	Avfall Norge, 7 September 2011, Hamar
Preliminary results from the Gaupen field experiment - changes in soil water chemistry after harvesting with and without removal of residues	Nicholas Clarke	Workshop on impacts of increased use of bioenergy – modelling and guidelines, Copenhagen, Denmark, 23-24 January 2012.
Modelling of the long-term experiments	Silje Skår, Holger Lange, Trine Sogn	Annual Meeting of the European Geosciences Union in Vienna
Sustainable Use of Forest Biomass for Energy: Possibilities and Problems	Nicholas Clarke	World Congress of Bioenergy, Dalian, China, 25-29 April 2011.
Short and long-term effects of whole-tree thinning on forest growth	Kjersti Holt Hanssen, Bjørn Tveite	Stjørdal, 8 September 2011
Analysis of the industrial wood use under A1 & B2 Energy scenarios with the EFI-GTM model	Alexander Moiseyev, Birger Solberg & Maarit Kallio	European Forest Sector Outlook ToS meeting, Geneva, 25 March 2011

Books

Table 17: List of books with contributions from CenBio in 2011

Book title	Chapter title	Author(s)
Biofuels: Alternative Feedstocks and Conversion Processes, A. Pandey et al. (eds.),	Principles of biorefinery	Cherubini F, Strømman AH
Sustainable Forest Management - Current Research Publisher: InTech.	Ecological consequences of increased biomass removal for bioenergy from boreal forests (submitted, printing delayed)	Nicholas Clarke

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Reports

Table 18: List of reports 2011

Title	Classification	Author(s)
Biomass resources in Norway	Restricted	Øivind Løken, Rune Eriksen, Rasmus Astrup and Tron Eid
Initial status report on unit costs and productivity estimates of relevant forest operation elements	Restricted	Bruce Talbot, Anders Hohle and Helmer Belbo
Bunting av veikantvirke	Public	Helmer Belbo and Leif Kjøstelsen
Recovery of logging residuals form final harvest in steep terrain	Public	Eirik Nordhagen
Wood ash as raw material for Portland cement	Restricted	Bjarte Øye
The effects of bromated flame retardants in the fuel mix on dioxin and furans formation (Literature study)	Restricted	Bjarne Malvik, Michael Becidan and Øyvind Skreiberg
Bioenergy laboratory development 2011	Restricted	Øyvind Skreiberg
Overview of gasification activities in GasBio and NordSynGas	Restricted	Liang Wang
Biogasspotensialet i norske biomasseressurser	Restricted	Tormod Briseid, Trond Knapp Haraldsen, Roar Linjordet, Roald Sørheim, Svein Jarle Horn and John Morken
Installation and start-up of the ChlorOut injection system	Restricted	Anders Hjörnhede, Åsa Astervik
Optimum technologies for medium- to large-scale biomass and MSW combustion and gasification CHP plants	Restricted	Øyvind Skreiberg
Emissions from BtE plants - Available data and need for new measurements	Restricted	Mette Bugge and Willy Horrigmo
Literature survey on NOx reduction measures in WtE and BtE plants	Restricted	Sigurd Sannan
Effects of forest harvesting on soil water chemistry: preliminary results from the Gaupen field experiment	Public	Nicholas Clarke
Evaluation of model changes necessary in EFI-GTM and NTM II for improved bioenergy analyses	Public	Alexander Moiseyev, Birger Solberg & Maarit Kallio

Media contributions

We have listed most of the contributions from CenBio personnel during 2011 in Norwegian media in Table 19.

Table 19: List of media contributions 2011

Media	Title	Author(s)
Bioenergi nr1 2011	Mer bioenergi med grønne sertifikater	Bolkesjal T.
Forrskning.no 25.feb.2011	Skog binder stadig mer karbon	Schare r J.
TU nr6 2011	Biogass fra søppel erstatter diesel	Cambi, Skje lhaugen
Forskning.no 4.apr.2011	Skogen kan bidra til redusert utslipp	Bøhn N.
Forskning.no 12.apr.2011	En helt gratis månelanding	Skjelhaugen, Langerud
SKOGeieren nr4 2011	Det vi driver med er uhyre viktig	Jahren I., Skjelhaugen O.J.
Forskning.no 9.mai 2011	Reine enzymer	Haraldsen 1., Eijsink V.
Forskning.no 12.mai 2011	Skog, hogst og klima	Kvaalen H.H.
Skog og Landskap Web 16.mai 2011	Ikke alltid størrelsen på flisfyringsanlegget som avgjør	Woxholtt S.

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Media	Title	Author(s)
SKOGeieren nr5 2011	14 TWh er mulig, men avhenger av lønnsomheten	Jahren I., Eid T.
UMB nytt nr1 2011	Fornybar energi tenner ungdom	Henriksen L., Heyerdahl P.H.
Forskning.no 13.mai 2011	Skittent biodrivstoff	Grønli K.S., Michelsen 0 .
Forskning.no 31 .mai 2011	Kan måle klimaeffekt av biobrensel	PilebergS., Cherubini F., Strømmen A.
Adresseavisa 17.jun.2011	Ny økologipris t il NTNU	Strømman A.
Bioenergi nr3 2011	Effekten av Enovatilskudd på energikilde	Lillemo SC et.al.
Bioenergi nr3 2011	Biomasse og potensiell energiproduksjon fra trær	Eid T. et.al.
UMB nett 6.sep.2011	Novozymes kjøper patentrettigheter av UMB	Eijsink V.
Forskning.no 16.sep.2011	Bra med hogst på kort sikt	Ursin Reed E. et.al.
Bondebladet 29.sep.2011	Framtida ligger i enzymer	Eijsink V. et.al.
Vestfold Blad 13.okt.2011	Bade gjødsel og matavfall må med	Briseid T. et.al.
DN innstikk 25.okt.2011	Verdier i gass. Biogass i vekst	Annonse

Deliverables list – Publications

AWP2011 included a total of 85 deliverables. Of these, 83 were planned to be finalised in 2011. Nine deliverables were delayed and transferred in February 2011 to the operative Deliverables list for 2011. Hence a total of 92 deliverables were scheduled to be finalised in 2011.

During 2011, 34 new deliverables were added to the 2011 Deliverables list. Some partners have produced more publications and report than planned. In some cases new publications with co-funding from CenBio have been added to the list, and in some cases a planned deliverable has been split in 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 20 below is therefore 124, with 122 deliverables due in 2011.

During the year, 25 deliverables were delayed for various reasons. Almost all delays and cancellations can be explained by the following three categories:
(1) delayed recruitments, (2) breakdown of instruments, and (3) delayed deliveries.
The delayed deliverables have been transferred to the 2012 Deliverables list.

In total, 95 deliverables were finalised in 2011.

Table 20: List of Deliverables 2011

Del. No	Deliverables title	Lead partner	Dated	New
D0.1.1_4	Annual Work Plan 2012	SINTEF-ER	2011-11-23	
D0.1.2_31	Progress report 1 2011	SINTEF-ER	2011-06-01	
D0.1.2_32	Progress report 2 2011	SINTEF-ER	2011-12-06	
D0.1.3_2	Accounts report 2010	SINTEF-ER	2011-02-04	
D0.1.3_3	Accounts report 2011	SINTEF-ER	2012-02-06	
D0.1.4_2	Annual report 2010	SINTEF-ER	2011-04-05	
D1.1.2	An assessment of woody biomass in Norway: Total availability and harvest residue cost-supply curves	NFLI	2012-03-01	
D1.1.4	Potential future biomass availability in Norway	UMB	Delayed	
D1.1.7	Potential future biomass availability in Norway (pop science article)	UMB	Delayed	
D1.1.8	Biomass resources in Norway	NFLI	2012-02-10	
D1.1.11	Masters thesis at UMB	UMB	Delayed	

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Del. No	Deliverables title	Lead partner	Dated	New
D1.1.12	Biomass expansion factors	NFLI	Delayed	
D1.2.1	Road Map: Defining the goals, roles and procedure for WP1.2	NFLI	2011-12-13	
D1.2.2	Initial status report on unit costs and productivity estimates of relevant forest operation elements	NFLI	2011-12-06	
D1.2.3	Technical survey report: an overview of biomass production and delivery systems in a Norwegian context	NFLI	Delayed	
D1.2.4	Efficiency of accumulating felling heads and harvesting heads in mechanized thinning og small diameter trees	NFLI	2011-12-13	
D1.2.5_1	Using Network Analysis in configuring appropriate biomass supply systems	NFLI	2011-04-13	
D1.2.5_2	Network involved in supplying woody biomass for energy	NFLI	2011-04-13	x
D1.2.6_1	Economic feasibility of road transport of forest fuels	NFLI	2011-10-18	
D1.2.6_2	Economic feasibility of road transport of forest fuels	NFLI	2011-10-18	x
D1.2.7	Economic evaluation of accumulating felling and harvesting heads in energy thinning	NFLI	2011-12-13	x
D1.2.9	Bunting av veikantvirke	NFLI	2011-12-13	x
D1.2.10	Recovery of logging residuals form final harvest in steep terrain	NFLI	2011-12-13	x
D1.3.3	Data about selected waste fractions characteristics	SINTEF-ER	Cont.	
D1.3.4	Combustion Properties of Norwegian Biomass: Wood Chips and Forest Residues	SINTEF-ER	2011-09-29	
D1.3.5	Influence of biomass' location and soil type in combustion characteristics	SINTEF-ER	Delayed	
D1.3.6_1	Modelling natural drying efficiency in covered and uncovered piles of whole broadleaf trees for energy use	NFLI	2012-01-05	
D1.3.6_2	Storage of whole trees and GROT	NFLI	2012-01-09	
D1.3.7	Modelling moisture content and dry matter loss during storage of logging residues for energy	NFLI	2012-03-02	
D1.4.2	Results from two green house experiments with ash based products (experiments carried out in 2010 and 2011)	BIOFORSK	Delayed	
D1.4.2_1	Quality requirements for wood ash as K component in recycled NPK fertilizers (Presentation)	BIOFORSK	2012-01-26	x
D1.4.2_2	Quality requirements for wood ash as K component in recycled NPK fertilizers (Proceedings)	BIOFORSK	2012-01-26	x
D1.4.2_3	Efficiency of organic NPK fertilizers combining N-rich organic wastes and bottom wood ash	BIOFORSK	2011-11-30	x
D1.4.2_4	Efficiency of organic NPK fertilizers combining N-rich organic wastes and bottom wood ash	BIOFORSK	2011-11-30	x
D1.4.2_5	Master thesis at UMB	BIOFORSK	2011-12-30	x
D1.4.5	Leaching of plant nutrients using waste based organic NPK fertilizers compared to mineral NPK fertilizers	BIOFORSK	Delayed	
D1.4.6	Use of ash based products for urban grey areas	BIOFORSK	Delayed	
D1.4.7	Wood ash as raw material for Portland cement	SINTEF-MC	2011-12-19	
D1.4.7_1	Askerelatert forskning innen CenBio Foreløpige resultater	BIOFORSK	2011-06-08	x
D1.4.7_2	Wood ash as raw material for Portland cement	SINTEF-MC	2012-01-26	x
D1.4.7_3	Wood ash as raw material for Portland cement Foreløpige resultater	SINTEF-MC	2012-01-06	x
D2.1.6	Additives and fuel mixes for reduced corrosion and fouling - Experimental study	SINTEF-ER	2012-02-02	
D2.1.7	The effects of bromated flame retardants in the fuel mix on dioxin and furans formation (Literature study)	SINTEF-ER	2011-05-31	
D2.1.9	Bioenergy laboratory development 2011	SINTEF-ER	2011-12-29	
D2.1.10	IEA Task 32 activity report	SINTEF-ER	2/year	
D2.1.11	Turbulent bluff body flows modeling using OpenFOAM technology	NTNU	2011-05-18	x
D2.1.12	Testing of OpenFOAM CFD code for plane turbulent bluff body flows within conventional URANS approach	NTNU	2011-05-18	x
D2.1.13_1	Experimental Investigation on Corrosion Abatement in Straw Combustion by Fuel Mixing	SINTEF-ER	2011-05-12	x
D2.1.13_2	The effect of kaolin on the combustion of demolition wood under well controlled conditions	SINTEF-ER	2011-11-11	x
D2.1.13_3	The effect of peat ash addition on the combustion of demolition wood under well controlled conditions	SINTEF-ER	2011-05-31	x

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Del. No	Deliverables title	Lead partner	Dated	New
D2.1.13_4	Optimal biomass mixtures to reduce corrosion and deposition: a thermodynamic analysis	SINTEF-ER	1900-01-00	x
D2.1.13_5	Ash related behaviour in staged and non-staged combustion of biomass fuels and fuel mixtures	SINTEF-ER	2012-02-05	x
D2.1.13_6	A critical review on additives to reduce potassium related operation problems in biomass combustion	NTNU	2012-02-22	x
D2.1.13_7	Effects of additive on barley straw and husk ashes sintering characteristics	NTNU	2012-02-22	x
D2.2.9	IEA Task 33 activity report	SINTEF-ER	2/year	
D2.2.10	Overview of gasification activities in GasBio and NordSynGas	SINTEF-ER	2012-03-09	
D2.3.5	Is elevated pressure required to achieve the theoretical fixed-carbon yield of charcoal from biomass? 1. Round Robin results for three different corn cob materials	SINTEF-ER	2011-03-22	
D2.3.6	Is elevated pressure required to achieve the theoretical fixed-carbon yield of charcoal from biomass? (new fuels)	SINTEF-ER	Delayed	
D2.3.8	Kinetics of corncob pyrolysis	NTNU	1900-01-00	x
D2.4.3	Biogasspotensialet i norske biomasseressurser	BIOFORSK	2011-04-30	
D2.4.6	IEA task 37 "Energy from biogas and landfil gas" Espen Govatsmark, Bioforsk. Minutes.	BIOFORSK	2011-11-28	
D2.4.7	Information flyer and PR	BIOFORSK	Delayed	
D2.4.8	Biogas production and saccharification of Salix pretreated at different steam explosion conditions	UMB	2012-03-02	
D2.4.9	Steam explosion on birch	UMB	Delayed	
D2.4.10	Workshop on pretreatment at Ås	BIOFORSK	2011-04-30	
D2.4.11	Effect of pretreatment on anaerobic digestion	BIOFORSK	Delayed	
D2.4.12	Effect of pretreated food waste on anaerobic digestion in combination with food waste	BIOFORSK	Delayed	
D2.4.13	Description of an expanded compositional analysis of CenBio relevant raw materials and key process fractions	Bioforsk/ UMB	Delayed	
D2.5.1	Torrefaction of Norwegian spruce and birch – An experimental study using macro-TGA	NTNU	2012-02-27	x
D3.1.4	Reports from standardization meetings	SINTEF-ER	x/year	
D3.1.5	Experimental results	SINTEF-ER	2012-02-10	
D3.2.5	R1 – efficiency formula for WtE	SINTEF-ER	2011-09-07	
D3.2.6	IEA Task 36 activity report	SINTEF-ER	2011-11-28	
D3.2.7	PREWIN activity report	SINTEF-ER	2011-12-14	
D3.3.2	Installation and start-up of the ChlorOut injection system	VRD	2011-03-31	
D3.3.3	Optimum technologies for medium- to large-scale biomass and MSW combustion and gasification CHP plants	SINTEF-ER	2011-12-29	
D3.3.4	Optimisation to achieve minimum corrosion rate and maximum NOx and CO reduction	VRD	Delayed	
D3.4.3	Emissions from BtE plants - Available data and need for new measurements	SINTEF-ER	2011-04-12	
D3.4.4	Literature survey on NOx reduction measures in WtE and BtE plants	SINTEF-ER	2011-12-02	
D3.4.5	Measurement campaign	SINTEF-ER	Delayed	
D4.1.8	Chemicals from lignocellulosic biomass: opportunities, perspectives, and potential of biorefinery systems	NTNU	2011-04-28	
D4.1.11	LCA-based comparisons of alternative uses of biomass	NTNU	Delayed	
D4.1.19	Climate impact of CO2 emissions from bioenergy: effect of management practices of boreal forests	NTNU	2011-05-31	
D4.1.20	Impact assessment of biodiversity and carbon pools from land use and land use changes in LCA, exemplified with forestry operations in Norway	NTNU	2011-05-01	
D4.1.21	Life Cycle Assessment of Bioenergy	NTNU	Delayed	
D4.1.22	Material, energy and environmental performance of technological and social systems under a Life Cycle Assessment perspective.	NTNU	2011-05-01	x
D4.1.23	Influence of rotation and anthropogenic storage periods on the climate impact of CO2 emissions from bioenergy	NTNU	2011-05-01	x
D4.1.24	GHG balances of bioenergy systems – Overview of key steps in the production chain and methodological concerns,	NTNU	2011-05-01	x

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Del. No	Deliverables title	Lead partner	Dated	New
D4.1.25	The biorefinery concept: using biomass instead of oil for producing energy and chemicals	NTNU	2011-05-01	x
D4.1.26	LCA of a biorefinery concept producing bioethanol, bioenergy and chemicals from switchgrass	NTNU	2011-05-01	x
D4.1.27	Principles of biorefinery	NTNU	2011-05-01	x
D4.2.3_1	Preliminary results from the Gaupen field experiment - changes in soil water chemistry after harvesting with and without removal of residues	NFLI	2012-01-31	x
D4.2.3_2	Effects of forest harvesting on soil water chemistry: preliminary results from the Gaupen field experiment	NFLI	2012-02-01	
D4.2.4	Modelling of the long-term experiments (Annual Meeting of the European Geosciences Union in Vienna)	NFLI	2011-04-12	
D4.2.5	Sustainable Use of Forest Biomass for Energy: Possibilities and Problems (Presentation at the World Congress of Bioenergy, Dalian, China)	NFLI	2011-04-27	
D4.2.6	Effects of different harvesting systems on soil fungi	NFLI	Delayed	
D4.2.7	Short and long-term effects of whole-tree thinning on forest growth	NFLI	2011-09-08	x
D4.2.8	Ecological consequences of increased biomass removal for bioenergy from boreal forests (Book chapter)	NFLI	2011-10-30	x
D4.3.2	Evaluation of model changes necessary in EFI-GTM and NTM II for improved bioenergy analyses	UMB	2011-xx-xx	
D4.3.8	Costs and production inputs of bioenergy production	UMB	Delayed	
D4.3.9	Demand and supply studies	UMB	Delayed	
D4.3.10	Impacts of EU RES policy on wood fibre supply and European forest industries	UMB	2011-12-30	
D4.3.11	Conceptual report on what is meant by sustainable bioenergy production, and discussion of corresponding criteria and indicators	UMB	Delayed	
D4.3.12	Analysis of the industrial wood use under A1 & B2 Energy scenarios with the EFI-GTM model	UMB	2011-04-27	
D4.3.13	Participation in EU-BioenergyNetwork (Bionet) III meetings	UMB	2011-09-30	
D4.3.14_1	Participation in meeting in IEA Task 40 International trade of biomass	UMB	2011-11-30	
D5.1.7	PhD seminar, CenBio graduate school	NTNU	2011-01-19	
D5.1.8	PhD seminar 2012, CenBio graduate school	NTNU	2012-01-27	
D5.1.9	First version, plan for collaboration on PhD education	NTNU	Delayed	
D5.2.9	1-3 business PhD applications	UMB	2011-11-15	
D5.2.10	5 industry workshops	UMB	2012-02-29	
D5.2.11	3 energy plants adjusted to research	UMB	2011-12-30	
D5.2.12	At least 10 scientific journal and conference articles to be submitted - At least 10 presentations to be produced (conference, seminar, workshop, etc)	UMB	2011-12-30	
D5.2.13	CenBio website	UMB+SE	Cont.	
D5.2.14	CenBio conference January 2012	UMB	2012-01-19	
D5.2.15	Other conferences, which to join, and in which way	UMB	2011-12-30	
D5.2.16	20 popular articles & press news and 10 presentations about CenBio	UMB+All	2011-12-30	
D5.2.17	New FME Brouchure 2011, revised CenBio info	UMB+All	2011-05-12	x
D5.3.1-v2	CenBio Innovation Plan, 2nd edition	SINTEF-ER	2011-12-20	
D5.3.4	Publishing and patenting processes	SINTEF-ER	Delayed	
D5.3.7	Award the first BIA	SINTEF-ER	2011-01-18	
D5.3.8	Status of CenBio innovations	SINTEF-ER	2011-12-02	
D5.3.9	Second Innovation workshop	SINTEF-ER	2011-09-06	

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List of partners – short names

For the sake of convenience unique short names for all partners have been defined. These can be found in Table 21.

Table 21: Short names of partners

No	Short name	Entity legal name
01	UMB	Universitetet for miljø- og biovitenskap (Host institution)
02	SINTER-ER	SINTEF Energi AS (Coordinating institution)
03	NTNU	Norges teknisk-naturvitenskapelige universitet NTNU
04	BIOFORSK	Bioforsk
05	NFLI	Norsk institutt for skog og landskap
06	SINTEF-MC	Stiftelsen SINTEF
07	VRD	Vattenfall Research and Development AB
08	AKERSHUS	Akershus Energi AS
09	SKOGEIER	Norges Skogeierforbund
10	AGDER	Agder Energi AS
11	NTE	NTE Holding AS
12	HAFSLUND	Hafslund ASA
13	STATKRAFT	Statkraft Varme AS
14	NSKOG	Norske Skogindustrier ASA
16	PROTEIN	Norsk Protein AS
17	AVFALLN	Avfall Norge
18	BONDELAG	Norges Bondelag
19	EGE	Oslo Kommune Energigjenvinningsetaten
21	VHN	Vattenfall Distribution and Sales, business unit Heat
22	ENERGOS	Energos AS
23	CAMBI	Cambi AS
24	JØTUL	Jøtul AS
25	BIONORDIC	BioNordic AS
26	GKAS	Granit Kleber AS

References

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

Annual Work Plan 2011
Annual Work Plan 2012

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

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