IEA Bioenergy

TASK 32
Biomass Combustion and Cofiring

FINAL TASK REPORT

2013 - 2015

Prepared by:

Jaap Koppejan, Task Leader
Procede Biomass BV
PO Box 328
7500 AH Enschede
The Netherlands
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Kees Kwant (Operating Agent)
RVO
PO Box 8242
3503 RE Utrecht
tel. + 31 88 602 2458
e-mail kees.kwant@rvo.nl

Introduction and aims of Task 32

Task 32 aims to stimulate the expansion of the use of Biomass Combustion and Cofiring for the production of heat and power to a wider scale. This objective is to be reached by generating and disseminating information on technical and on non-technical barriers and solutions.

Some general trends for the different combustion applications are:

- Manually fired stoves and boilers using firewood logs are still widely deployed in both OECD countries and non-OECD countries. Health issues related to combustion aerosols is one of the main concerns.
- Fully automated combustion technologies for wood pellets and wood chips are widely applied and continuously improving in terms of reliability, costs and environmental performance. Significant development work is ongoing for enabling the use of locally available, low grade biomass residues;
- Biomass based CHP plants based on grate combustion are widely deployed in Scandinavian countries, Austria, Switzerland, Italy, Germany and to a lesser extent USA and France. These systems are generally of increasing scale and have increasing electrical efficiency due to increased understanding of superheater corrosion mechanisms;
- CHP plants based on fluid bed combustion in the size of 20-100 MW_e can be considered as well established technology, especially deployed in Finland and Sweden but increasingly in other countries as well;
- The co-firing of biomass with coal is widely deployed in a number of European countries and is of increasing interest worldwide. There is also a trend towards the conversion of existing coal-fired boilers to 100% biomass firing.

Task 32 has contributed to further development and implementation of biomass combustion and cofiring systems in its member countries by exchange of information during semi-annually organised Task meetings, Task organized workshop on particular topics (with active industry involvement and eventually organized with other tasks or networks), as well as Task initiated studies on certain specific combustion related topics such as aerosols emissions and cofiring. In these activities, Task 32 seeks industrial participation, interaction with other Bioenergy Tasks, other IEA Implementing Agreements and European bioenergy industry organisations. A memorandum of understanding for collaboration exists with the industrial biomass power group of VGB Powertech (the European branche organisation of power producers). Several joint workshops and studies were carried out with such other groups, as shown in this report.

Summary of topics addressed

In the triennium 2013-2015, Task 32 addressed most of the issues listed above in specific workshops or publications. The following specific activities were undertaken:

Task meetings

7 task meetings were held, to effectively communicate progress and results of both national R&D programmes and task initiated projects described in this end-of-task report. Each task meeting was combined with plant visits and/or a task organised workshop on a specific combustion related topic.

Workshops

Five workshops were organised, typically in combination with a task meeting. Through the hyperlinks in the below table, detailed information can be obtained from the Task 32 website.

Nr.	Topic	Hyperlink
D2	Expert workshop on CFD for design of industrial biomass combustion technologies, 6 June 2013, Copenhagen, Denmark	Individual presentations
D9	Torrefaction workshop at the Central European Biomass Conference, 17 Jan 2014, Graz, Austria	Individual presentations Summary report
D6	High Temperature Corrosion in Biomass Combustion Installations, 4 June 2014, Jönköping, Sweden	Individual presentations
	Expert workshop on Opportunities for Bioenergy in South Africa, 4 Nov 2014, Johannesburg, South Africa	Individual presentations
D16	Expert workshop on Highly Efficient and Clean Wood Log Stoves, 29 Oct 2015, Berlin, Germany	Individual presentations
	Key results of Task 32 in the triennium 2013-2015, Berlin, 28 Nov 2015	Individual presentations

As compared to the original workplan some deviations occurred. A planned workshop on biomass cofiring was cancelled, while an additional workshop was organised on opportunities for bioenergy in South Africa. Further, Task 32 co-organised or provided input to conference sessions initiated by others such as:

- Presentations on combustion of challenging fuels and health and safety at a VGB Powertech on key challenges in biomass power production, 13-14 Nov 2013.
- A presentation on the commercial status of torrefaction at the World Bioenergy Conference, 27 Jan 2015
- A conference session in the IEA Bioenergy conference, Berlin, Nov 2015 displaying the key results of the triennium 2013-2015

Task studies:

Task 32 prepared a number of specific publications in which recent R&D developments were collated in order to address the mentioned actual market issues. An overview of these specific activities that were performed by task 32 in the triennium 2013-2015 is given below. A detailed description per activity is enclosed in the annex.

Nr.	Deliverable
D11	Developments in commercialisation of torrefaction technologies, Marcel Cremers, DNV-GL, Netherlands
D13	Advanced characterisation methods for solid biomass fuels, Ingwald Obernberger, Thomas Brunner, TU Graz, Austria
D17	The status of large scale biomass firing - The milling and combustion of biomass materials in large pulverised coal boilers. W.R. Livingston, J. Middelkamp, W. Willeboer, S. Tosney, B. Sander, S. Madrali, M.T. Hansen, J. Koppejan and M.F.G. Cremers
D18	Sensitivity of System Design on Heat Distribution Costs in District Heating, Thomas Nussbaumer and Stefan Thalmann, Verenum, Switzerland Status Report on District Heating Systems in IEA Bioenergy T32 member countries, Thomas Nussbaumer and Stefan Thalmann, Verenum, Switzerland

Nr.	Deliverable
D19	Techno-economic evaluation of selected decentralised CHP applications based on biomass combustion with steam turbine and ORC processes, Alfred Hammerschmid, Bios Bioenergiesysteme GmbH, Austria
D20	Database on cofiring experiences

Workshops

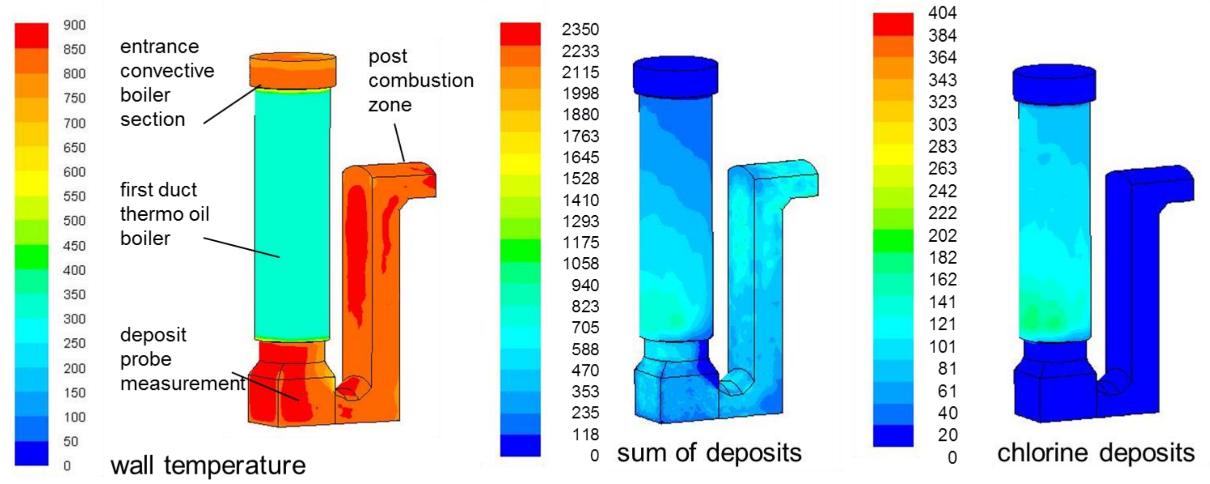
A summary of the results of the workshops performed is provided below, reports on all workshops can be downloaded from the Tasks website www.ieabioenergytask32.com .

1. Fuel characterisation, pretreatment, and supply

A workshop on progress in commercialisation of Torrefaction Technologies was held jointly with Task 40 and the EU project 'SECTOR' at the Central European Biomass Conference, 17 Jan 2014, Graz, Austria. It was concluded here that in 2010-2014, expectations about the commercialisation rate of torrefaction technologies were unrealistically high. It takes several years to develop a new thermal processing technology from technology concept to full scale production and have a substantial impact on the world market. Nevertheless, significant progress has been achieved, as a number of technology suppliers are now able to produce high quality torrefied material and commercially offer turnkey torrefaction plants at full scale. The progress in commercialisation of torrefaction was also examined in a separate T32 report, see below.

2. CFD based furnace and boiler design

On June 6, 2013 a workshop was held as a side event of the EU Biomass Conference to share experiences and address the current opportunities and limitations of CFD based design of industrial biomass combustion appliances. CFD aided design tools are becoming increasingly available to translate the improved fundamental understanding of the combustion process into better practical designs. At the workshop it was concluded that such CFD tools can be very effective in improving the design of such equipment, as it can lead to much better combustion quality, avoid the need of a 'try and error' approach and reduce development expenses. The application of such tools however is relatively costly and it is doubtful whether smaller stove producers can already afford this at the moment, at the moment this approach is therefore more applied for larger scale industrial boilers.



Example of CFD applications:Simulation of deposit formation in a 10 MW thermal oil boiler (Robert Scharler, Bioenergy2020+)

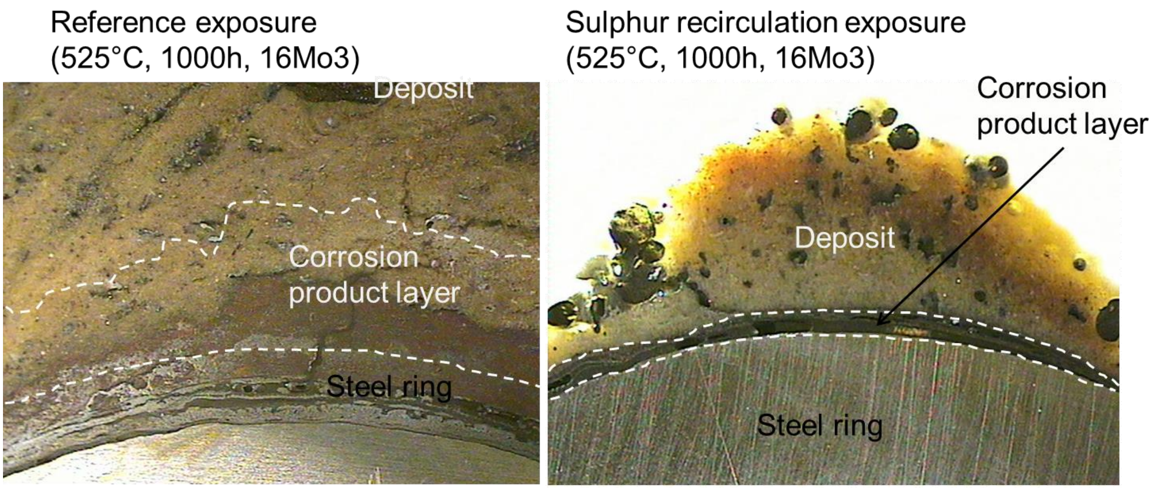
3. Improvement in woodstove designs

The second workshop addressed recent technical developments in design of domestic woodstoves at the IEA Bioenergy Conference, Oct 2015. Wood stoves continue to be sold on the European market and provide significantly to renewable energy use, however, in case obsolete technologies are applied or the stove is not properly operated, there may be significant adverse effects on public health. Some important conclusions from this event:

- Good combustion starts with a properly designed combustion chamber (if possible using CFD tools). Only in the second stage, manufacturers should design an attractive casing around it (currently the design process often takes place the other way around).
- Very positive results have been achieved with stoves equipped with automatic combustion control, to optimise the combustion parameters through the various phases of the combustion process. For the validation of such improvements also new test procedures are required, which better reflect real life operational behaviour, such methods are currently being developed.
- Since recently, positive results have also been achieved for the application of catalysts in stoves. In Germany, stove catalysts with a proven long lifetime are now commercialised. The effect of foam ceramic elements without catalyst, aimed at extending the reaction time and thereby reducing the emission of particles, seems only marginal.
- Other major influencing factors on emissions are the use of wood with suitable moisture content, proper user behaviour and an adequate installation and integration of the stove into the building. These factors should be addressed by user trainings organized by stove suppliers and by quality certification schemes for installers.

4. High Temperature Corrosion in Biomass Combustion Installations

On 4 June 2014, a workshop was organised at the World Bioenergy Conference in Jönköping, Sweden on high temperature corrosion attacks in biomass boilers. This topic continues to be relevant as industry wants to use inexpensive but therefore often challenging biomass types at the highest possible high steam (and therefore metal) temperatures and the lowest CAPEX and OPEX costs. The workshop provided an overview of the fundamental mechanisms behind high temperature corrosion, as well as a number of practical ways to mitigate the corrosion to acceptable levels, such as fuel additives, furnace additives, wall cladding, superheater configurations, etc.



Experiments to evaluate the protective effect of sulphur recycling on metal corrosion (Prof L.G. Johansson, Chalmers University)

5. South African national workshop on opportunities for biomass based power generation

4 November 2014, IEA Bioenergy Task 32 and ESKOM jointly organised an expert workshop on the opportunities for bioenergy in South Africa. The workshop aimed at discussing the potential for applying various bioenergy technologies in the South African economy. After various presentations and an open discussion, it was concluded that particularly biomass cofiring could make a significant impact in South Africa, but also landfill gas and anaerobic digestion could be very relevant.

6. Key results of 2013-2015

The key results of projects carried out by Task 32 in the triennium 2013-2015 as summarised in this report were presented at the IEA Bioenergy conference, Berlin, 28 Nov 2015. This provided an opportunity to display the work of Task 32.

Task 32 Studies

A summary of the contents of task 32 studies carried out in the triennium 2013-2015 is provided below. The full reports are available on the Task 32 website.

1. Status overview of Torrefaction Technologies - A review of the commercialisation status of biomass torrefaction, Marcel Cremers et. al., DNV-GL, Netherlands (D11)

This report provides an update of the Status overview of torrefaction technologies, which was produced by IEA Bioenergy Task 32 in 2012. The reason for this action was the observation that commercialisation of torrefaction technologies has been more difficult than anticipated in 2012, when it was expected that a significant fraction of the biomass pellets supplied today could have been replaced by torrefied pellets. It has been hard to fully prove the claims made earlier on product characteristics, and several companies have gone bankrupt due to inability to produce good quality product or due to a lack of buyers.

Nevertheless, it is clear that the companies involved have significantly improved their ability to produce high quality products, with pellets of comparable durability to conventional wood pellets. The torrefied pellets exhibit comparable supply costs, however end users should be convinced that the claimed superior handling and combustion characteristics do translate into an economic advantage that can counterbalance the perceived risk.

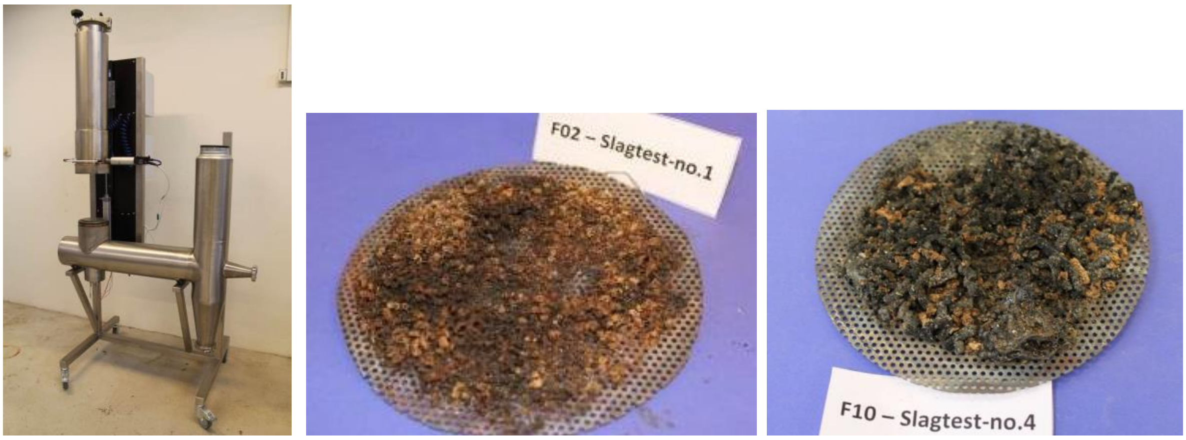
As for conventional wood pellets, price parity with coal is essential to enable commercial market introduction of torrefied biomass for co-firing. In the absence of a substantial price penalty for CO_2

emissions and with the low price level of coal, this implies that typically additional subsidy schemes should be in place.

2. **Advanced characterisation methods for solid biomass fuels, Ingwald Obernberger, Thomas Brunner, TU Graz, Austria (D13)**

In this project a comprehensive questionnaire regarding advanced biomass fuel characterisation methods was distributed to different organisations active in this field. Based on this feedback as well as on information and experiences gained from recent European projects (EU FP7 and ERA-NET Bioenergy), a summary and evaluation of different advanced fuel characterisation methods has been made. The advanced methods concerned are TGA analyses, fuel indexes, chemical fractionation, SEM/EDX analyses, TGA/DSC analyses, thermodynamic equilibrium calculations as well as test runs at batch and continuously working reactors. All these methods show their specific advantages and disadvantages and therefore, in many cases a combination of different methods is envisaged.

It can generally be recommended to apply the evaluation of fuel indexes as a first step in fuel characterisation in order to gain a qualitative pre-evaluation of conversion related problems to be expected.



A slag analyser used to predict slagging behaviour of a fuel (DTI, Denmark)

In a second step, test runs in batchwise or continuously operated lab-scale reactors are recommended in order to gain quantitative data. The selection of the reactor, the test run setup as well as the measurement and analyses program has to be adjusted to the specific problems expected from the utilisation of the fuel (derived from the interpretation of fuel indexes) as well as the constraints of the process where it shall in future be applied. TGA, chemical fractionation, SEM/EDX analyses, STA-tests as well as TEC can be used as supporting tools to gain deeper insights into specific aspects as well as to gain basic data (e.g. kinetic data) for process modelling. If a new fuel has been positively evaluated by these methods with regard to an application in real-scale it is recommended to finally perform a pilot-scale test run with this fuel. Thereby, the plant settings can already be optimised based on the results gained from the advanced fuel characterisation.

3. **The status of large scale biomass firing - The milling and combustion of biomass materials in large pulverised coal boilers. W.R. Livingston, J. Middelkamp, W. Willeboer, S. Tosney, B. Sander, S. Madrali, M.T. Hansen, J. Koppejan and M.F.G. Cremers, jan 2016 (D17)**

This report provides a status update on biomass cofiring activities. It describes the practical experiences and commonly accepted approaches for biomass cofiring in pulverised coal fired power stations, including a number of case studies.

Firing and co-firing biomass as a replacement for coal in large pulverised coal boilers is a very attractive option for generating electricity from biomass, offering various technical and commercial advantages, such as:

- The capital investment requirements of power plant conversion projects are very much lower than the investment costs of a new build power plant,
- The reliability and security of the supply of the power generated are higher than most other forms of renewable energy, and
- The power generation efficiency and the generation costs are much better than those associated with industrial scale biomass power plants.

The report shows how the key technical options for the conversion of large pulverised coal boilers to the firing and co-firing of biomass have been successfully demonstrated, principally in projects in Northern Europe, over the past 10-15 years or so. A number of the plants converted to biomass firing and co-firing are currently in operation, and there are a small number of further conversion projects currently in the proposal stage.

The general experience from these projects has been that the technical risk areas have been managed successfully and that the plant availability and efficiency levels after conversion have been acceptable.
It has been found that the storage and handling of the biomass materials, and particularly the tendency of the biomass to generate significant dust levels, have presented the most significant problems. It is fair to say, however, that the fuel suppliers and the materials handling equipment supply industry have learned many lessons over the past few years, and that the solutions currently being offered for biomass projects represent a significant improvement over previous practice.

Aerial view of de converted Drax power station, showing the coal stockpile on the bottom left and the four biomass silos on the bottom right

4. Sensitivity of System Design on Heat Distribution Costs in District Heating, Thomas Nussbaumer and Stefan Thalmann, Verenum, Switzerland (D18a)

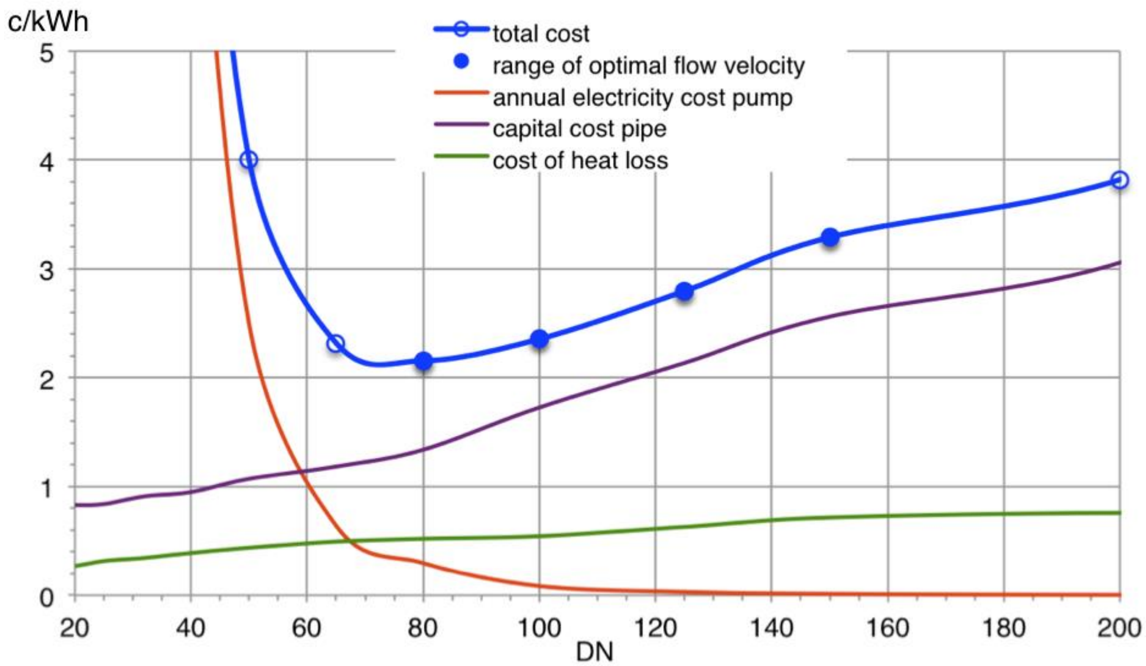
District heating (DH) offers interesting opportunities to use biomass heat to replace decentralised fossil heating. The additional cost and energy losses caused by the heat distribution network however can be significant in comparison to the benefits. In close collaboration with the IEA District Heating and Cooling Agreement, a study was performed to evaluate how biomass combustion based district heating networks can be optimally designed. The project resulted in two separate reports.

The first report comprises a sensitivity analysis for a virtual DH network in Switzerland with 1 MW heat output, a pipeline length of 1 km, and a heat consumption during 2000 annual full-load hours corresponding to a linear heat density of 2000 MWh per year and meter of pipeline length.

The economic assessment evaluates influences of capital costs, electricity prices, interest rates, fuel prices, insulation, supply and return temperatures, full load hours, etc. It clearly indicates that for the case analysed, capital costs are most relevant for the total costs of heat supply, representing a share of 62%, while the fuel costs at a fuel price of 4.0 c/kWh contributes with 25% and the electricity costs for pumping at a power price of 16.5 c/kWh with the remaining 13%. An assessment of the connection load reveals that at constant linear heat density, the heat distribution costs increase with increasing network size. Consequently, strong economy of scale in the heat production is necessary to justify large DH systems. This pre-condition is typically fulfilled by automatic biomass combustion plants and even amplified for applications with combined heat and power (CHP).

Since the capital costs dominate the total cost, minimisation of the heat distribution costs generally implies the use of the smallest, technically feasible pipe diameter without cavitation pitting and while respecting the maximum allowable specific pressure drop up to 300 Pa/m are recommended, since this only occurs at a short peak time. For the investigated model network, an oversizing by one diameter resulted in 9% higher heat distribution cost while two diameters cause 30% higher cost.

Besides the pipe diameter, it is essential to minimise the flows by obtaining the lowest possible return temperatures. Further, the insulation class only has a minor influence on the economy and high insulation is not economically favourable at today's fuel prices.



Heat distribution losses indicated as total cost and divided in capital cost, heat loss costs, and electricity costs as function of the nominal diameter for a reference case.

5. Status Report on District Heating Systems in IEA Bioenergy T32 member countries, Thomas Nussbaumer and Stefan Thalmann, Verenum, Switzerland (D18b)

The second report evaluates district heating systems in Task 32 member countries based on characteristic parameters such as annual heat losses, linear heat density and the connection load. Data was evaluated from 800 district heating systems from Austria, Denmark, Finland, Germany and Switzerland.

As the evaluation illustrates that heat losses can increase significantly with reducing linear heat density, therefore a minimum linear heat density of 1.8 MWh/am is recommended. The survey also shows that the heat losses vary by more than a factor of three with a given linear heat density. This is caused by various factors:

- Applying too pipes with too large diameters strongly affects the capital costs and heat distribution losses and should be avoided.
- Other key parameters that determine heat supply costs are network layout, temperature spread and level, insulation class, and the utilisation of the network.

While the costs of heat production generally benefits from a strong economy of scale, the heat distribution is related to diseconomy of scale. Consequently, larger district heating systems as e.g. in Denmark, are only economically feasible due to the large economy of scale in the generation unit.

A detailed analysis of individual line sections for a selected number of district heating systems in Switzerland revealed that 80% of the line sections are oversized mostly by one or two and maximally up to four nominal diameters. This results in heat distribution losses and costs of up to 20% resp 30% higher than necessary.

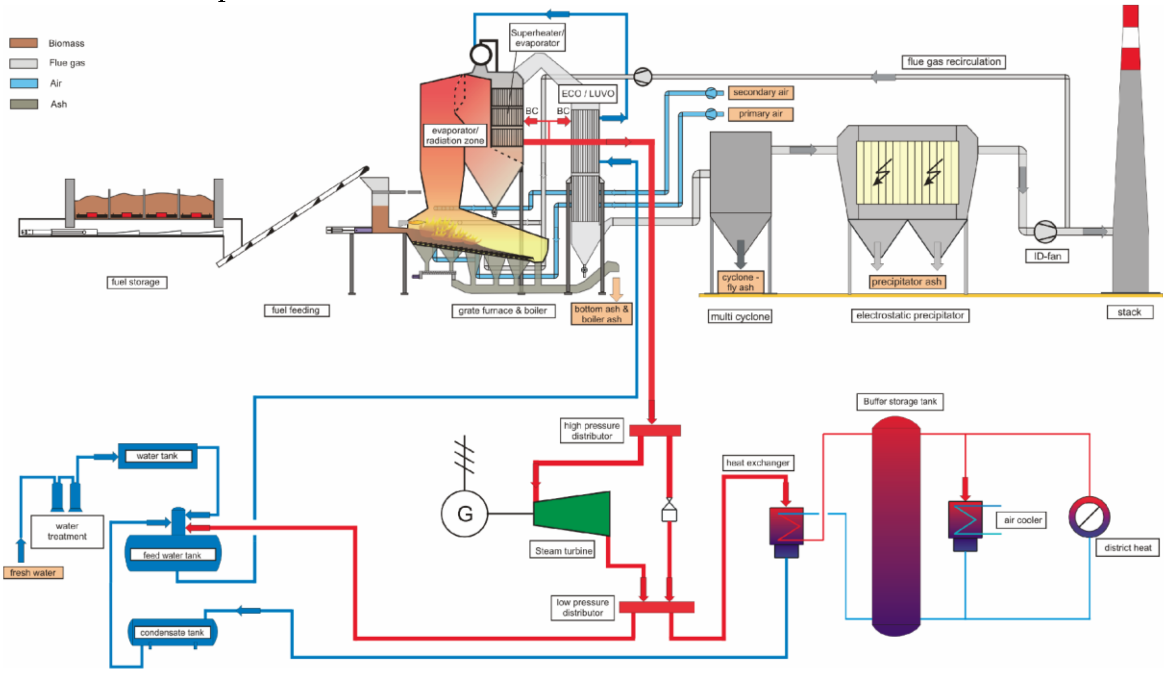
6. Techno-economic evaluation of selected decentralised CHP applications based on biomass combustion with steam turbine and ORC processes, Alfred Hammerschmid, Bios Bioenergiesysteme GmbH, Austria (D19)

Since the first CHP plant based on biomass combustion has been launched, several technological developments and demonstration activities have taken place. This report provides an update of a T32 project carried out in 2004, covering three actual plants that were recently taken into operation, based on steam turbine and ORC processes:

- In steam turbine based systems, the main issue within the last ten years was an increase in electric efficiency by increasing the life steam temperatures through better materials used that can withstand high temperature corrosion. Within the present study the economics of a steam turbine based CHP plant of 5.7 MWel,gross from Austria was evaluated.
- ORC based CHP plants have been operational since 1999, and today over 200 ORC units are in operation with continuously improved electric efficiency and reduced investment costs. A typical ORC plant of 2.4 MWe in Estonia was evaluated in this study.
- A third plant evaluated was based on the so-called direct exchange ORC system. This technology is based on an ORC system without the need of an intermediate circuit (e.g. a thermal oil cycle) and can be seen as a promising future approach to reduce the investment costs of this technology. A case study based on the direct exchange ORC system in a biomass plant in Slovakia with an electric capacity of 130 kWel,gross has been investigated.

The analysis of the CHP technologies covers their technological as well as an economic performance evaluation based on real life figures of the case studies selected. This includes their process flow sheets with mass and energy balances, and the specific differences between the technologies concerning operation behaviour, personal demand and process control.

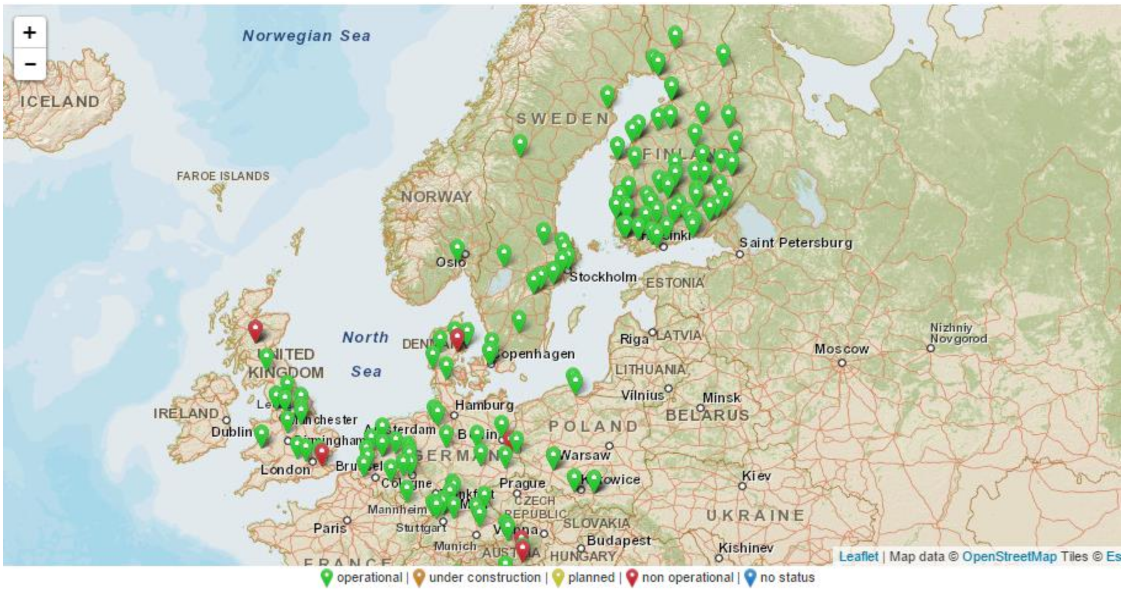
The report showed, that the heat generation costs of the different CHP plants investigated vary between 44 €/MWh_{th} (steam turbine) to 25 €/MWh_{th} (direct exchange ORC system) and the electricity generation costs are in a range of 150 €/MWh$_e$ (direct exchange ORC) and 99 €/MWh$_{el}$ (steam turbine). The main cost factors are the capital costs and the fuel costs. The economy of scale effect is clearly obvious when comparing the specific investment costs of the 130 kW$_{el,gross}$ ORC with the 2.4 MW$_{el,gross}$ ORC. This illustrates that higher feed in tariffs or investment subsidies would be required in order to make the smaller CHP technologies economically viable. The study further shows that heat utilisation and correct dimensioning of the CHP plant is crucial in order to achieve a large number of the full load operating hours in heat controlled operation.



Schematic diagram of the evaluated biomass CHP plant based on steam turbine in Austria

7. Updated database on biomass co-firing with expert tool (D20)

On the T32 website, a database exhibiting experiences with biomass cofiring is operational since 2003. Currently approximately 250 coal fired power plants are identified with experience in cofiring biomass. In 2015, the database was incorporated into the joint IEA Bioenergy Technology database.



Geographical detail of entries in the Task 32 cofiring database..

Summary and outlook for Task 32

Task 32 has a unique role to provide an independent platform for hand-on information exchange amongst both manufacturers and operators of biomass combustion plants, and to translate findings of fundamental and applied R&D work to industry and policy makers.

In the period 2013-2015, Task 32 organised several expert workshops and produced a number of topical reports. The work of Task 32 is greatly appreciated by market actors (end users, equipment suppliers and policy makers), as indicated in the interaction in the workshops organised and from the feedback on reports published. One success factor is the provision of publications with detailed insight on key technical performance figures on costs, reliability, efficiencies, and emissions from various technology concepts such as torrefaction, CFD analysis tools, low emission stoves and boilers, new particle removal technologies, or mitigating high temperature corrosion.

The work of Task 32will continue in the triennium 2016-2018, with an increased number of participating member countries and a new work programme that reflects the actual research priorities in the area of biomass combustion and cofiring.

TASK 32 MEMBERS DURING THE TRIENNIUM 2013-2015

AUSTRIA

Ingwald Obernberger
Inst. for Resource Efficient and Sust. Systems
Working group thermal biomass utilization
Technical University of Graz
Inffeldgasse 21b
A - 8010 GRAZ
Austria
tel +43 316 481300 12
fax +43 316 481300 4
ingwald.obernberger@tugraz.at
www.tugraz.at

BELGIUM

Mike Temmerman
Walloon Agricultural Research Centre
146, chaussée de Namur
5030, Gembloux
tel. +32 81 62 71 57
temmerman@cra.wallonie.be

DENMARK

Morten Tony Hansen
Force Technology
Hjortekærsvej 99
DK-2800 Lyngby
Denmark
tel. + 45 72 15 77 55
fax + 45 72 15 77 01
mth@force.dk
www.force.dk

GERMANY

Hans Hartmann
Technologie- und Forderzentrum
Schulgasse 18
D-94315 Straubing
Germany
tel: +49 9421300112
fax: +49 9421 300211
hans.hartmann@tfz.bayern.de
www.tfz.bayern.de

IRELAND

William Smith
University College of Dublin
UCD School of Mechanical and Materials Engineering
University College Dublin
Belfield, Dublin 4
Ireland
tel: +353 (1) 716 1902
william.smith@ucd.ie
www.ucd.ie

JAPAN

Nobuyuki Tahara
New Energy and Industrial Technology Development Organization (NEDO)
18F Muza Kawasaki Building
1310 Omiya-cho, Saiwai-ku
Kawasaki City
Kanagawa 212-8554
tel +81-44-520-5271
fax +81-44-520-5275
taharanby@nedo.go.jp
www.nedo.go.jp/

NETHERLANDS

Jaap Koppejan (Task Leader)
Procede Biomass BV
PO Box 328
7500 AH Enschede
The Netherlands
Tel +31 53 489 4636
Fax +31 53 489 5399
jaapkoppejan@procede.nl
www.procede.nl

Kees Kwant (Operating Agent)
RVO
PO Box 8242
3503 RE Utrecht
tel. + 31 88 602 2458
e-mail kees.kwant@rvo.nl

NORWAY

Øyvind Skreiberg,
SINTEF Energy Research AS
Sem Sælands vei 11
NO 7465 Trondheim
tel +47 735 93993
fax +47 735 92889
Oyvind.Skreiberg@sintef.no
www.sintef.no

SOUTH AFRICA

Yokesh Singh
ESKOM
RSA P.O. BOX 1091
Johannesburg | 2000
Tel: 011 800 3491
Cell: 082 417 1167
singhy@eskom.co.za
www.eskom.co.za

SWEDEN

Claes Tullin
SP Technical Research Institute of Sweden
Energy Technology
Box 857
S-501 15 Borås
tel. +46 10 516 55 55
fax +46 33 13 19 79
claes.tullin@sp.se
www.sp.se

SWITZERLAND

Thomas Nussbaumer
VERENUM
Langmauerstrasse 109
CH-8006 ZÜRICH
Switzerland
tel +41 44 377 70 71
fax +41 44 377 70 77
thomas.nussbaumer@verenum.ch
www.verenum.ch

UK

William R. Livingston
Group leader - fuel technology
Doosan Babcock Energy Limited
Technology Centre
High Street
Renfrew PA4 8UW
Scotland, UK
tel +44 141 8864141
fax +44 141 8853370
blivingston@doosanbabcock.com
www.doosanbabcock.com