BIOENERGY 2013

Conference and Exhibition

From 4th to 6th of September 2013

Jyväskylä, Finland

BOOK OF PROCEEDINGS

www.bioenergy2013.fi

Bioenergy 2013 Book of Proceedings

Bioenergia ry, Benet Ltd.
Jyväskylä
2013
ISBN 978-952-67890-1-9

THE BIOENERGY ASSOCIATION OF FINLAND – NATURAL ENERGY FROM FINLAND

- The Bioenergy Association represents the interests of the bioenergy sector in Finland
- The association has over 200 member organisations
- It represents the entire bioenergy sector from land ownership to forest and energy companies, and technology and research in the field
- The association aims to promote the preconditions of the production, use, competitiveness and economy of bioenergy and peat. It fosters expertise and know-how in the sector and co-operation between its members, and improves the general operating preconditions of the industry
- The Bioenergy Association of Finland promotes the use of renewable and domestic energy to create new jobs in Finland, to support sustainable development, and to promote the well-being of people and the environment for future generations through the use of bioenergy
- Through its operations, the association aims to increase the share of renewable and domestic energy to half of the entire energy consumption of Finland
- Our member companies produce 80 per cent of all renewable energy in Finland and employ over 20,000 people either directly or indirectly
- Total net sales of its member companies amount to almost three billion euros
- The association supervises the interests of its members and represents them when dealing with the key decision-makers of the sector

Summary of main services

- Interest representation of the bioenergy sector in Finland and the EU
- Media relations and conveying messages from members to the media
- Informing members of the energy policy and legislation
- Industry reports
- Studies and research in the field
- Seminars in the field
- Meetings between decision-makers
- Bioenergia magazine
- Newsletter to stakeholders
- Newsletter to members
- News bulletin on the bioenergy sector

Bioenergia

The Bioenergy Association of Finland

Kaisaniemenkatu 4, 00100 Helsinki, FINLAND

www.bioenergia.fi

BENET LTD.

Benet Ltd. is a private consulting company that has experience in cost efficient bioenergy operations. Benet can flexible combine with local knowledge to produce economically, environmentally and socially sustainable solutions. We have years of experience of energy handling consulting, smart use of energy counseling, organizing of events and joint stands for fairs.

Products

- Energy handling consulting
- Smart use of energy counseling
- Organizing of events and joint stands for fairs.

Benet Ltd.

Piippukatu 11, 40100 JYVÄSKYLÄ, FINLAND

http://www.benet.fi/

TABLE OF CONTENT

BIOMASS COMBUSTION AND POWER

CHEMICAL BIOMASS CONVERSION PRODUCTS

PROCESSES FOR SOLID, LIQUID AND GASEOUS FUELS FROM BIOMASS

BUSINESS CONCEPTS AND DEMOSTRATION

BIOENERGY 2013 CONFERENCE - A WARM WELCOME!

The progress of bioenergy technology has been enormous. Bioenergy is a safe, local, effective and renewable energy source. At the same time, markets are getting more and more global.

New innovations exist, but challenges and bureaucratic barriers also still exist. Bioenergy and biofuels are global answers, global potentials and global visions for sustainable energy production and use, not only in dreams but in actuality.

In Finland you can see modern bioenergy plants and technologies everywhere in practice, from farm size up to the world´s biggest biomass power plant. Finn-made combined heat and power (CHP) plants, and modern harvesting and transport technologies for biomass are known worldwide. Other areas are developing fast as well biogas-related knowledge, torrefaction etc, etc.

Through these breakthrough technology, Finland aims to increase the total sustainable use of renewables from a ca. 30 % up to 38% by the year 2020. At the same time our energy related cleantech industry is able to get important references for new technology.

Finland wants to show and deliver the updated knowledge and practical experiences we have in the field of bioenergy.
Many universities, institutes, schools and private companies provide education and training in energy and bioenergy know-how and technology, from the practical field courses to the highest level of scientific research.

The Bioenergy Association of Finland wants to thank all partners for planning and making the BIOENERGY 2013 Conference a reality for all of us. The Conference is arranged by The Bioenergy Association and Benet Oy in co-operation with Jyväskylä Paviljonki and Jyväskylä Fair organisations.

Special thanks to International and National Conference Committees and to our member organizations, which have extended considerable efforts to build up this Conference with its side events.

Warm commendations also to our other international partners: the European Biomass Association (AEBIOM) and World Bioenergy Association (WBA) spreading the message.

The organization of the Conference is possible with participation of the Sponsors. The Sponsors are: Metso, Vapo, Protacon, Jyväskylä Innovation Ltd, JAMK University of applied science and Jyväskylä Region Centre of Expertise Programme.

Additionally our media partners are the magazines The Bioenergy International and EnergiaUutiset.

Also many companies and organizations with their bioenergy specialists have supplied their inputs by arranging site visits for us, like: StoraEnso, Fortum, Gasum, Joutsan Ekokaasu, Mikko Kylmälahti, Lievestuoreen Lämpö, Ääneseudun Biolämpö, ProPellet, Turos Team, Toholammin Energia, Tampereen Energiantuotanto and Halesa.

Finally the organizers thank the City of Jyväskylä and the Mayor Mr. Markku Andersson for the long-standing support and beautiful surroundings.

Bioenergy is the global winner in the energy business. May this Bioenergy 2013 Conference with Social Programmes, Study Tours and the Bioenergy Exhibition play an important role in terms of providing up-to-date information and expertise in general, and special know-how support for policy- and decision-making in particular.

The Bioenergy Association wishes to You successful Conference Days here in Jyväskylä.

A warm welcome!
Mr. Jyrki Peisa
Managing Director
The Bioenergy Association of Finland

THE GLOBAL POSITION OF BIOENERGY IN A CLIMATE COMPATIBLE ENERGY SYSTEM

Dr. Heinz Kopetz
Chairman, World Bioenergy Association
Austria

Abstract:

Different drivers support the development of renewable energies such as bioenergy: the import dependence on fossil fuels, their upcoming scarcity in parts of the world, their environmental impact. The latter is the most important driver. A 4° C warmer world can only be avoided if fossil fuels are replaced by renewables within a few decades. In such a climate compatible energy system biomass will have to come up for 25 -35% of the energy demand.

The potential for such an increased use of biomass exists: the better use of by-products coming from agriculture, forestry and the food industry, the better use of waste, more biomass from sustainable managed forests and an increased contribution of agriculture. The big challenge for governments policies lies in setting up stable framework conditions that mobilize this potential and favor an economic and efficient use of biomass be it predominantly for heat, electricity or transport fuels. The priorities differ from region to region from country to country, yet in each contry biomass will have to play an increasing role in the future low carbon energy system.

In developing countries where biomass covers more than 60% of the energy supply better efficiency and sustainable supply structures have to be implemented. In developed countries the penetration of the energy markets with bioenergy is as important as the research and the development for new technologies.

BIOGRAPHY

Heinz Kopetz, graduated from the University of Life Sciences in Vienna and the Iowa State University, USA in economics (1966). He served as managing director of an agricultural agency in Austria. In the eighties he developed the concept of the farmer as energy producer and implemented financial and educational programs in this field.
He was engaged in different positions related to energy such as:.
2005 – 2010 Chairman of the European Biomass Association (AEBIOM), Brussels
1977 – 2002 member of the supervisory board of the Styrian public utility for electricity and district heating, Graz
1997 – 2000 Member of the advisory committee for Energy of the European Commission, Brussels
Heinz Kopetz, Austria, at present president of the World Bioenergy Association, works with issues such as potential, sustainability, carbon neutrality, efficient utilisation of Biomass

BIOMASS POLICIES

EU NATIONAL RENEWABLE ENERGYS ACTION PLANS PROGRESS

Dan Asplund
Benet Oy
dan.asplund@benet.fi

ABSTRACT: The Renewable Energy Directive 2009/28/EC established a European framework for the promotion of renewable energy, setting mandatory national renewable energy targets for achieving a 20% share of renewable energy in the final energy consumption and a 10% share of energy from renewable sources in transport.The directive required the Member States in 2010 to develop action plans that represent milestones to heat, electricity and transport fuels, and how each member country is to achieve its renewable energy goals. Member States are also required to submit action plans related to progress reports every two years.

This paper present the results of the first progress reports.The paper present general results on the EU level and detailed results from nine countries.The countries was selected with consultations with finnish companies.Generally theese countries are on the target track.

1 INTRODUCTION

The Renewable Energy Directive 2009/28/EC ("the Directive") established a European framework for the promotion of renewable energy, setting mandatory national renewable energy targets for achieving a 20% share of renewable energy in the final energy consumption and a 10% share of energy from renewable sources in transport. All biofuels used for compliance with the 10% target and that benefit from national support are required to comply with the scheme.

Directive (2009/28/EC) required the Member States in 2010 to develop action plans that represent milestones to heat, electricity and transport fuels, and how each member country is to achieve its renewable energy goals. Member States are also required to submit action plans related to progress reports every two years.

The general part of this paper is based on the progress report by the EU comission on Member States' progress in the promotion and use of renewable energy along the trajectory towards the 2020 targets. The assessment covers recent developments and is based on the latest Eurostat data on renewable energy (for 2009 and 2010), Member State renewable energy progress reports submitted to the Commission in 2011[i].

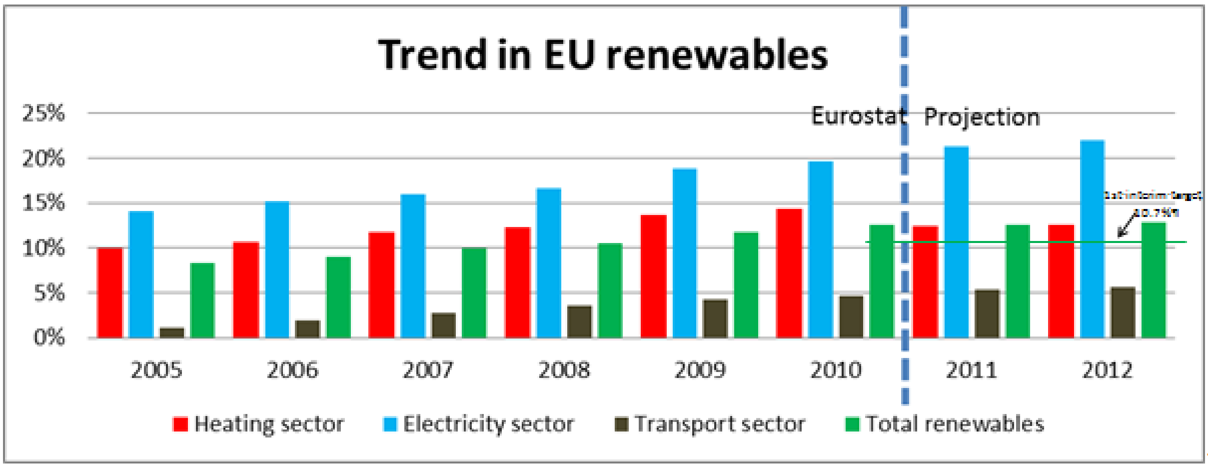
The country status is based on results from a project carried out by Benet ltd and financed by several energy knowledge centers: Jyväskylä Innovation Oy,Prizztech Oy, Oy Merinova Ab, Imatran seudun kehitysyhtiö Oy, Hermia Oy, Varkaus seudun osaamiskeskus/ LUT and Joensuun Tiedepuisto Oy.The companies selected 8 countries for the analysis of the progress reports.

2 GENERAL RESULTS

2.1 Progress in renewable energy development

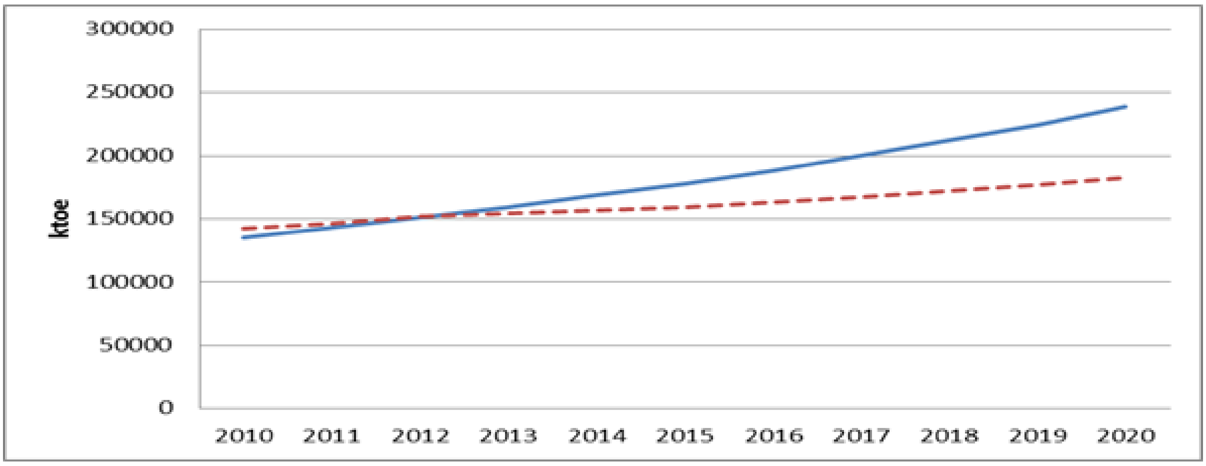
With the implementation of the Renewable Energy Directive and national policies set out in National Renewable Energy Action plans ("plans"), most Member States experienced significant growth in renewable energy since the Commission's last progress report[ii].

Sectoral and overall growth of renewable energy in the EU (Eurostat)



In fact, the 2010 renewable energy shares of 20 Member States and the EU as a whole were at the level of or above 2010 commitments set out in their national plans and above the first interim target for 2011/2012(1).

Planned (blue) versus estimated (red/dotted) trend in EU renewable energy



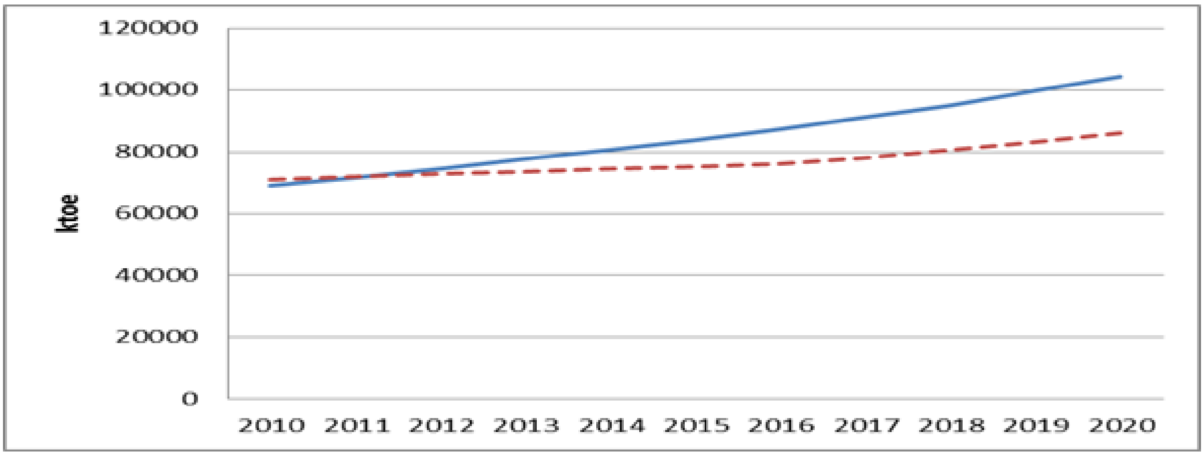
This conclusion is underpinned by the sectoral developments in electricity, heating and cooling and transport. 15 Member States failed to reach their indicative 2010 targets for the share of renewable energy in the electricity mix. In the transport sector, 22 Member States failed to achieve their indicative 2010 target of 5.75%.

The heating and cooling sector has not had any, even indicative targets, and has experienced slow growth since 2005. Moreover the analysis undertaken for the Commission suggests that the share of renewable energy in the heating and cooling sector may actually *decline* in the coming years.

Despite the recent strong growth in the onshore wind industry of recent years, Member States' plans for onshore wind production 354 TWh may fall short. Further efforts will be needed to reinforce measures and improve infrastructure, or only an estimated 210 TWh might be achieved.

For all **biomass**, the trend is also negative but not as extreme as for wind:

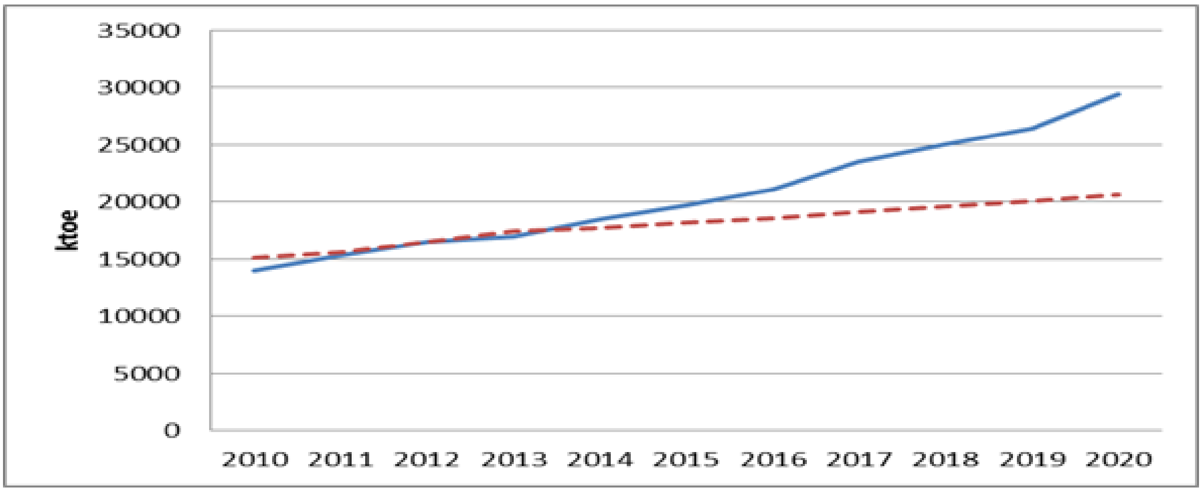
Planned (blue) versus estimated (red/dotted) trend in EU biomass energy



Here, however, the scale of production in the sector is far greater than for wind or solar power. Planned production is intended to reach 104 mtoe by 2020 (for both the electricity (232 TWh or 19 mtoe) and heating sectors (around 85 mtoe), compared however, to *expected* production for 2020 of 86 mtoe. This deviation could be linked to the production cycles of the wood, pulp and paper industries, whose wastes and residues constitute a significant part of biomass feedstock. The Commission's intended report on biomass and sustainability will explore this matter in greater depth[iii].

For biofuels (biomass consumed in the transport sector), the prognosis is more like that of biomass in general: a slight surplus over the planned trajectory will decline and, unless further measures are taken, will result in a deficit. In addition, the Commission has proposed an amendment to the 10% target for renewable energy in the transport sector, requiring greater use of non-food feedstock to contribute towards the target. Greater reliance on advanced feedstock (which produces higher greenhouse gas savings than food-related feedstock) clearly requires additional measures for the target to be reached.

Planned (blue) versus estimated (red/dotted) trend in EU biofuels



From all of the above data it can be concluded that overall, by sector and across technology, there has been a strong initial start in EU renewables growth under the new regime of the Renewable Energy Directive. However, as we look at their future evolution, it seems that the economic crisis is now affecting the renewable energy sector, particularly its cost of capital, as it has all other sectors of the economy. This, combined with ongoing administrative barriers, delayed investment in infrastructure and disruptive changes to support schemes, means further efforts are needed to achieve the 2020 targets.

When assessing national results for the initial, interim targets, it must be recalled that the 2010 plans and 2011/2012 interim targets are just the starting point of the trajectory that gets steeper towards 2020. In fact, if the growth rates achieved in 2009/2010 were maintained to 2020, eleven Member States would still fail to reach their target. In many Member States currently implemented policies (chiefly sub optimal support schemes and addressing administrative barriers) risk being insufficient to trigger the required renewable energy deployment to reach the 2020 targets. The financial crisis also affects these developments, since the cost of capital has risen in several Member States. Thus low cost measures that reduce administrative burdens and that increase energy efficiency (lowering total energy demand and therefore raising the share of renewable energy) are even more important policies for achieving the targets.

A summary of current national performance is contained in the following table.

Member State	2005 RES share	2010 RES share	1st interim target	2020 RES target
Austria	23.3%	30.1%	25.4%	34%
Belgium	2.2%	5.4%	4.4%	13%
Bulgaria	9.4%	13.8%	10.7%	16%
Cyprus	2.9%	5.7%	4.9%	13%
Czech Republic	6.1%	9.4%	7.5%	13%
Germany	5.8%	11.0%	8.2%	18%
Denmark	17%	22.2%	19.6%	30%
Estonia	18%	24.3%	19.4%	25%
Greece	6.9%	9.7%	9.1%	18%
Spain	8.7%	13.8%	10.9%	20%
Finland	28.5%	33%	30.4%	38%
France	10.3%	13.5%	12.8%	23%
Hungary	4.3%	8.8%	6.0%	13%
Ireland	3.1%	5.8%	5.7%	16%
Italy	5.2%	10.4%	7.6%	17%
Lithuania	15%	19.7%	16.6%	23%
Luxembourg	0.9%	3%	2.9%	11%
Latvia	32.6%	32.6%	34.0%	40%
Malta	0%	0.4%	2.0%	10%
Netherlands	2.4%	3.8%	4.7%	14%
Poland	7.2%	9.5%	8.8%	15%
Portugal	20.5%	24.6%	22.6%	31%
Romania	17.8%	23.6%	19.0%	24%
Sweden	39.8%	49.1%	41.6%	49%
Slovenia	16.0%	19.9%	17.8%	25%
Slovakia	6.7%	9.8%	8.2%	14%
UK	1.3%	3.3%	4.0%	15%
EU	8.5%	**12.7%**	**10.7%**	**20%**

Progress towards the first interim target:

>2% above interim target

<1% from or <2% above interim target

>1% below interim target

2.2 Policy measures

Until such time as Europe has achieved an open and competitive single energy market, with market failures corrected and external costs internalised, policy measures, be they financial, regulatory or administrative, are needed to boost the growth of renewable energy. Europe is still striving to make the energy market work. Market failures include fragmented markets, low levels of competition, and significant external costs related to climate change, environmental pollution, security of supply, and technological innovation (spill over effects and first move advantages). To compensate for the market failures, Europe has a range of policy measures in place including support schemes, standards, and administrative rules to promote renewable energy development.

Direct EU measures to support renewable energy include EU R&D expenditure and the allocation of revenues from the sale of ETS allowances (the

"NER300" programme). The scope to promote innovative technologies in the future will be explored in the Commission's forthcoming Communication on energy technologies and innovation. In addition, the key European instrument for internalising the external costs of climate change, the EU ETS, is entering its third phase. To date, however, the (low) carbon price has not provided investors with sufficient incentive and has not succeeded in being a major driver towards long term low carbon investments.

The Commission's analysis of Member States' 2011 progress reports[iv] indicates that progress in removing the administrative barriers is still limited and slow. There are concerns about slow progress regarding online applications, administrative time limits for planning and permitting decisions, and transparent approval processes. The availability of a single administrative body for dealing with renewable energy project authorizations and assistance to applicants is still limited. Only Greece and Portugal reported newly introduced "one-stop-shop-agencies" since the plans were published; a few Member States had them in place before for some technologies (e.g. wind) or in some parts of the country (e.g. in Germany or in Sweden). Only Denmark, Italy and the Netherlands have a single permit system for all projects. These concerns are particularly acute in the heating and cooling sector, where the disparate nature of the different possible technologies hinders the development of uniform administrative approaches.

Sub optimal administrative arrangements clearly raise the costs of renewable energy and their removal normally has low fiscal implications: simplifying and speeding up administrative procedures does not need to cost public administrations more, and the reduction in uncertainty and regulatory risk for investors can significantly reduce the cost of capital. For energy transmission infrastructure, such measures have been addressed at European level through the regulation on guidelines for trans-European infrastructure which defines responsibilities for coordinating and overseeing the permit granting process, sets minimum standards for transparency and public participation and fixes the maximum allowed duration of the permit granting process

<u>The Electricity Grid</u>

Renewable energy for generating electricity must be integrated into the market. However some of the major future renewable energy sources – mainly wind and solar power – have inherently different characteristics from conventional sources in terms of cost structure, dispatch ability and size, and cannot simply "fit" into existing market structures without any adaptation. Infrastructure investments are clearly and urgently needed and electricity grid operations also need to be updated.

Article 16 of the Directive requires reforms of electricity infrastructure, operation and development and the rules for grid access and cost sharing, with a view to increasing the contribution of electricity from renewable energy sources. Member States are also required to report on these reforms. Analysis of Member State progress in ensuring the transmission and distribution of electricity from renewable sources and the improvement of the renewable energy integration rules indicates that most Member States have made some progress in tackling their grid barriers. However, further progress improving the transparency and consistency of network rules is still needed.

Given the longer term expectations of the growing share of EU electricity coming from renewable energy sources, full implementation of Article 16 of the Directive is important. The current failure to modernise the grid as the energy mix is changing is causing problems for the development of the internal market, technical problems related to loop flows, grid stability and growing power curtailment, and investment bottlenecks resulting from delayed connection of new power producers. Adaptation of the electricity grid and system operation, including by improving storage capacity, better system controls and forecasting will improve the efficiency with which current infrastructure is used. And more efficient use and management of the grid can also avoid transport losses. Together with rapid progress in implementing the Member States' Ten Year Network Development Plan and in determining and starting the Projects of Common Interest established under the regulation on guidelines for trans-European energy infrastructure, such improvements are necessary for the equal treatment of renewable energy and the proper integration of renewable energy producers into the electricity market.

Arrangements and cost sharing rules for *using* the grid also need modernising to reflect the changing nature of the electricity generation mix and progressively increase the balancing responsibility of renewable energy producers as dispatchable electricity producers. The final aim should be that renewable energy is fully competitive and that producers act and are treated as equal market players. The increase of transparency and equitable grid connection and the development of cost sharing rules will provide the incentives on all producers to improve system-wide efficiency and not to make production decisions or location decisions in isolation.

It should also be recalled that infrastructure concerns for clean energy are not limited to the electricity sector. The need to reduce fossil fuel dependence in the transport sector also requires new infrastructure investments. So to foster the deployment of alternative fuels infrastructure in transport, the Commission has published the 'Clean Power for Transport' package[v] proposing a Directive on the deployment of alternative fuels infrastructure including binding targets for infrastructure uptake.

<u>Support schemes</u>

There has been a discussion about the effectiveness and the efficiency of different types of renewable energy support schemes for at least a decade. Multiple schemes exist, with good and bad features and impacts. In 2011 the Commission suggested guidance would be useful to help Member States identify best practice[ii]. Following discussions with Member States, the Commission's 2012 report "Renewable Energy: a major player in the European energy market" [vi] announced plans to produce such guidance. Given the prominent role that financial support schemes play in developing renewable energy today, and given the growing prominence (and cost) of renewable energy use in the electricity sector, urgent efforts are needed to reform support schemes to ensure that they are designed in *a cost effective, market-oriented manner*. The Commission's guidance is necessary to ensure that support schemes are adjusted regularly and quickly enough to take account of falling technology costs and to ensure reforms make renewable energy producers part of the energy market (such as by moving from feed in tariffs to feed in premiums or quotas, and using tendering to avoid over compensation etc.); to ensure such market interventions are correcting market failures and not adding or maintaining market distortions. The Commission's forthcoming revision of state aid guidelines will also take this into account. Regarding the uncertainty of support schemes for biofuels in particular, the lack of progress on the adoption by the Council of a new legal framework for taxation of energy products[vii] is a concern, since the scope to use tax incentives would expire by 2020 under the current legal framework.

Many national reforms have had a negative impact on the investment climate. Most critical have been changes that reduce the return on investments *already made*. Such changes alter the legitimate expectations of business and clearly discourage investment, at a time when significantly more investment is needed. Thus there is a need for guidance on the reform process itself, to ensure support schemes are cost effective but not disruptive. The Commission also feels more action is needed to ensure convergence and the Europeanisation of energy: in addition to developing common approaches to supporting renewable energy, growing cross-border cooperation must occur. The current legal framework for such cooperation is the Renewable Energy Directive's cooperation mechanism framework. This includes joint projects, where common approaches can be developed based on specific renewable energy projects, technologies or regions as well as joint support schemes such as the Swedish-Norwegian scheme, feasible within well connected regional markets where consumers will also physically profit from renewable energy capacity installed in a neighbouring country. Such instruments provide the pathway to the *European* development of renewable energy, where resource development in a single energy market occurs on a common and cost effective basis. To this end, in addition to the forthcoming guidance on cooperation mechanisms, the Commission will promote the emergence of regional (and possibly sectoral) joint support schemes between Member States based on cooperation mechanism, such as a common, *European* approach to offshore wind development in the northern seas).

Table 2. Suppoer measures in different EU countries.

		AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
Sähkö	Syöttötariffi	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x			x			x	x	x
	Preemiot					x		x	x	x											x					x		
	Kiintiö-velvoite		x													x						x		x	x			x
	Investointiavustukset		x		x	x					x		x	x			x	x	x	x								
	Verovapautukset		x							x	x		x						x		x	x			x		x	x
	Verotukselliset kannustimet			x			x		x											x	x	x				x		
Lämmitys	Investointiavustukset	x	x	x	x	x	x		x		x		x	x	x		x	x	x	x	x	x	x		x	x	x	x
	Verovapautukset	x	x					x				x	x			x	x				x				x			x
	Verotukselliset kannustimet			x			x		x			x											x					
Liikenn	Kiintiö-velvoite	x		x	x	x	x	x		x	x	x			x		x	x	x		x	x	x	x		x	x	x
	Verovapautukset	x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x

3 COUNTRY RESULTS

3.1 German

Germany has made good progress in line with the objectives, the UE's share of total consumption (11.3% in 2010, the goal of 9.5% in 2012). Heating and electrical power are well above the target, as well as a bit of traffic.

Heating:
Geothermal has increased, but is lagging far behind, the sun has risen and is slightly behind, the solid biomass is a renewable largest source of well over target, biogas has grown manifold and has a double objective, bioliquids has increased and is significantly above the target systems and heat pumps is close to the objective.

electricity:
The objective of hydropower is a small decrease, but it has grown a little bit. The importance of solar power is very small, but in the objective. Wind power (terrestrial) target is very challenging but the goal is a bit crossed. Marine wind power target is also challenging, and there is a considerable way. Solid biomass and biogas are the second largest sources and their growth has been high, and the target is slightly exceeded, especially in biogas (double)

Transport:
Biodiesel is clearly a great source, and its share has grown to almost objective. Bio-ethanol has increased multi-fold and the number is double that target. UE electricity use has increased, but is still considerably below the target.

3.2 Poland

Poland has proceeded in accordance with the UE's total consumption (9.5% in 2010, the 2012 target of 9.3%). Heating is being over the target, and the target almost in electricity transport lag behind

Heating:
Geothermal is lagging behind, the sun is modest and far behind the solid biomass is well above the target, the biogas is lagging behind, and heat pumps is virtually objective.

Electricity:
The objective is small hydropower growth and it has been realized. The importance of solar power is very small, and it is the objective.
Wind power (terrestrial) target is very challenging. Despite the significant increase it is off target. Solid biomass and biogas, are renewable, and the largest source of growth has been substantial and has a target on both sides.

Transport:
In particular, biodiesel has grown and is one of bioethanol with the target.

3.3 Sweden

Sweden is more than the objectives of the UE's total consumption (47.8% in 2010, 49% of the 2012 target). Heating and electricity are also well above the target and the traffic just over the target.

Heating:
The sun is modest, but over the target. Solid biomass is well above the target, the biogas is more than four times and heat pumps is more than three times the target.

Electricity:
Overall, we are lagging behind the number. The aim of hydro power is small and the reduction is realized. The importance of solar power is very small, and it is the objective. Wind power (terrestrial) target is very challenging and there is a little behind. Solid biomass is the second-largest hydroelectric power source and its growth has been significant, is the objective. Bio-gas and bio-oil are clearly lagging behind.

Transport:
Bioethanol is the largest source of and a little behind the target. Biodiesel has grown significantly and is more than double over the target. Biogas plants grown significantly and it is more than the target.Layout of the text

3.4 Estonia

Estonia has progressed well over the objectives and is close to the 2020 targets in all sectors except transport (24% of total consumption in 2010, the 2012 target of 18.7%).

Heating:
Solid biomass is the only source, and has developed well over the target. The use of biogas has been started in 2010.

Electricity:
Hydropower is the objective of 50% growth in 2020 and the 2012 target has been achieved. Wind power (terrestrial) target is very challenging. Despite the significant increase has reached only a little over half of the target. Solid biomass has grown significantly and in 2010 exceeded its 2020 target. The use of biogas has increased, but it is not set goals.

Transport:
In particular, bioethanol has increased, but is falling

short of the 2012 target. Biodiesel is also increased, but it is significantly lagging the target.3.4 Headings

3.5 Latvia

Latvia has not proceeded according to the UE's total consumption (32.5% in 2010, the goal of 34.5% in 2012). Heating and electrical power is behind the target, but the traffic is being objective.

Heating:
The sun and the air pump to the target is modest, but there is no production in 2010. Solid biomass is by far the largest source, and it has grown and is the objective. Biogas has increased, but behind the target.

Electricity:
The objective of hydropower is a small increase, and it has already been exceeded. Solar power is a small target, but the production has not started. Wind power (terrestrial) target is very challenging, but it has not grown. Wind power (marine) is the goal, but the production has not been yet. Solid biomass is grown, but there is a significant lag behind the target. Biogas production has increased, but is falling short of the target.

Transport:
Bio-diesel and bio-ethanol use has grown and is the objective.

3.6 Lithuania

Lithuania has already exceeded the target of the UE's share of total consumption (19.7% in 2010, 17.3% of the 2012 target). Heating is being over the target, a bit off the target in electricity and transport, a bit above the target.

Heating:
Geothermal is a bit grown up and close to the target. The sun is a modest goal, but the production has not started. Solid biomass is well above the target and the biogas has increased, but behind the times. Heat pumps have a modest goal, but the production has not started ..

Electricity:
The objective of hydropower is a small increase, but it has not materialized. Solar power is also a modest goal, but the production has not started. Wind power (terrestrial) target is very challenging in 2020, and the objective of being. Solid biomass has increased significantly, but the target is behind. Biogas has grown many times, but we are lagging behind the target.

Transport:
Both biodiesel and bio-ethanol use has increased, but in both cases, the objective of being behind the times.

3.7 Great Britain

Great Britain has proceeded incrementally, but the achievement of the objectives is unlikely. UE's total consumption (3.3% in 2010, the 2012 target of 4.4%). Heating and electricity are lagging far behind target. Traffic is being the target.

Heating:
Geothermal has grown a bit, but it is not the objective. The sun has risen significantly, and the target for 2020 has already been achieved. Bio-energy has definitely increased, but well behind the target. Heat pumps has increased, but well behind the target.

Electricity:
The objective of hydropower is a small increase, but it has not materialized. Solar electricity is a major goal, and it is far from the target. Wave energy is a difficult goal, but it is far away. Wind power (terrestrial) target is very challenging. Despite the significant increase it is off target. Biomass is grown, but it is off target.

Transport:
In particular, biodiesel increased and exceeded the 2012 target. Bioethanol has increased, but it is only in the middle of the target.

3.8 France

France has proceeded according to UE's total consumption (12.8% in 2010, the target for 2012 of 13%). Heating and electrical power are a bit behind the times. Traffic is being over the target, but the target is below the EU target proposed for 2010)

Heating:
Geothermal has declined since 2005, and the target is clearly behind. The sun has risen significantly, but the target has been achieved only one-third. Heat pumps have increased significantly and are well above the target, as well as an air pump and ground source heat pumps). Solid biomass is grown and is the objective. Biogas has increased, but well behind the target for the year 2012.

Electricity:
Hydro power has diminished and it is off target. Geothermal has been reduced, and well behind the target. Solar electricity is a significant increase, but it is far off the target. Wind power (terrestrial) target is very challenging, however, the growth has been significant, but the target is behind. Solid biomass has increased slightly and is behind the target. The use of biogas has grown well, but it is still behind the target.

Transport:
In particular, biodiesel has increased and is above the target. Also, bioethanol has increased and is above the target.

3.9 Spain

Spain has proceeded according to UE's total consumption (13.5% in 2010, the 2012 target of 12%). Heating and electrical power are above the target,

Heating:
Geothermal is a modest, but behind the times. The sun has risen significantly, but it is off target. Solid biomass is grown and is slightly above the target. Biogas is behind the target in 2012. Heat pumps are close to the objective.

Electricity:
Hydro power is reduced and it is off target. Solar significant increase, but it is off target. Wind power (terrestrial) target is very challenging. The growth has been significant, but we are lagging behind the target. Solid biomass is grown well, but it is off target. The use of biogas has increased slightly, but is still considerably below the target.

Transport:
In particular, biodiesel has increased and is above the target. Also, bioethanol has increased and is above the target.

4. References

[1] Member State biennial renewable energy progress reports (2011): http://ec.europa.eu/energy/renewables/reports/2011_en.htm
[1] Renewable Energy: progressing towards the 2020 target (COM (2011) 31 and SEC (2011) 130)
[1] In COM(2010)11 the Commission committed to reporting on the impacts of biomass sustainability regimes.
[1] Member State biennial renewable energy progress reports (2011): http://ec.europa.eu/energy/renewables/reports/2011_en.htm
[1] (COM(2013) 18 final) http://ec.europa.eu/transport/themes/urban/cpt/index_en.htm
[1] COM(2012)271
[1] Commission proposal for revision the Energy Taxation Directive COM(2011) 169 final.

BIOENERGY IN GERMANY: TECHNOLOGY OVERVIEW, PRACTICAL EXPERIENCE, ECONOMICAL FEASIBILITY AND FUTURE PERSPECTIVES

Strzalka R., Schneider D., Eicker U.
Stuttgart University of Applied Sciences,
Schellingstrasse 24, D-70174 Stuttgart, Germany
Tel.: +49/77/8926-2674, Fax: +49/711/8926-5698,
Email: rafal.strzalka@hft-stuttgart.de

ABSTRACT: The limited potentials of fossil fuels and the rising energy demand are the main reasons for a growing interest in the use of solid, liquid and gaseous biofuels for energy purposes. Among the renewable energy sources biomass is the only carbon-based renewable fuel and can therefore be used to provide a significant part of the energy demand if environmental and economical effective technologies are introduced. It is believed that energetic utilization of biomass will become a vital contributor to Germany's future energy supply.

In general there are six main biomass conversion technologies which include; direct combustion for heat and power; gasification for syngas; pyrolisis for biochar, gas and oils; anaerobic digestion for methane rich gas; fermentation of sugars for alcohols; and oil extraction for biodiesel. The work presented in the paper provides a review of opportunities and barriers for the six generic energy conversion technologies based on biomass within Germany.

While numerous new plants for the transformation of biomass into usable forms of energy were installed in recent years in Germany, the practical experience shows that not all technologies are reliable and cost efficient. Some of the recently applied solutions are compared on the basis of efficiency, economical feasibility and practical experience.

Keywords: Bioenergy, CHP, biofuels

1 DIRECT COMBUSTION FOR HEAT AND POWER

Bioenergy provides a significant part of the global energy demand and creates with 80% by far the biggest share of the energy generated by renewable sources. Among the technologies for conversion of biomass to useful forms of energy biomass combustion is the main technology route and has a 90% share of globally installed bioenergy capacity [1][2]. The main advantages of biomass combustion appliances are their high efficiency and the cost-efficiency of biomass burning systems. Biomass boilers and furnaces are available in a wide power range from a few kW up to more than 100 MW [3].

In the recent years rapid technological progress has been made in the research and development of biomass combustion equipment with respect to the combustion efficiency and reduction of the environmental impact of biomass burning appliances. If operated in a sustainable manner energy generation systems based on biomass combustion can contribute to an improvement of the quality of environment in the respective regions. The sustainability of energy generation from biomass can in particular be achieved by using natural biomass fuel sources in combination with newly developed control systems of modern biomass boilers [4]. The relatively low cost of fossil fuels and the relatively high investment cost of biomass combustion based plants are the main reason why bioenergy does not contribute a higher proportion of the energy generated in the EU.

The biomass potentials are limited and hence the utilization of biomass has to be characterized by high efficiency. Today biomass is most efficiently used in decentralized cogeneration plants as they combine high efficiency with reasonable fuel transport distances. The technologies for decentralized cogeneration have the unique advantages of reducing the environmental impact of power generation and increasing the effectiveness of biomass utilization [5][6]. Among commercial available technologies the ORC-modules (Organic Rankine Cycle) and Stirling engines are the only commercialized technologies for heat and power production from biomass in decentralized cogeneration plants.

1.1 ORC plants

The most well-proven and commercial available technology for decentralized cogeneration based on biomass combustion is the Organic Rankine Cycle with its main advantages, which are excellent part-load operation and reduced operating costs. The principle of energy generation with the

ORC technology is similar to the classical water-steam process, with the main difference that instead of water an organic fluid (silicone-oil) is used as the working medium. The utilization of silicone oil as the working fluid has the advantage that electricity can be generated at much lower temperature and pressure in comparison to the water-steam process. Due to the favorable operating parameters a significant reduction of the investment and maintenance costs can be achieved [7].

The ORC plant is a closed system which is connected to a heat source. Thermal-oil is mainly used as a heat transport medium between the heat source and the evaporator of the cogeneration module. Thermal energy produced in a biomass combustion appliance is used to generate superheated organic steam in the evaporator. The steam flows to the turbine which is connected to a generator. The condensation of steam takes place in the condenser and the waste heat from the electricity production process is utilized as district heat. The electrical efficiency of ORC systems ranges between 6 and 17% and is linked with the maximum heat recovery and the thermal efficiency of the boiler [8].

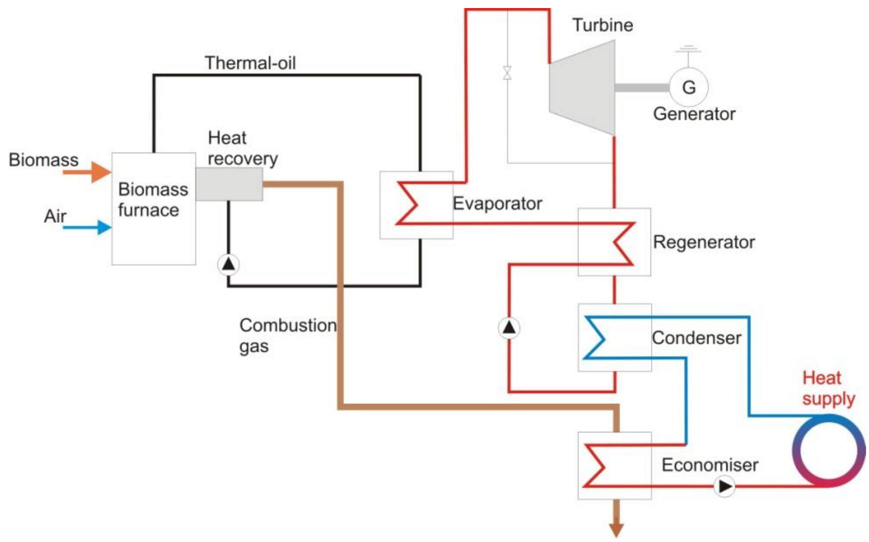


Figure 1. ORC plant based on biomass combustion.

More than 150 biomass cogeneration plants based on the ORC technology have been installed in Europe. The majority (85) of the ORC modules in power output range between 0.2 and 3.1 MW_{el} have been installed in Germany. Many of the ORC plants are used in decentralized cogeneration schemes where they fed their sink heat into district heating systems [9][10].

The ORC modules have several positive properties in comparison to the classical water-steam power generation plants. The main advantages of the ORC technology are favorable operating conditions of the turbine, excellent part-load behavior, long operating time and high level of automation. Although the ORC technology is already highly advanced, detailed information of the long term performance of biomass combustion based plants are still rare.

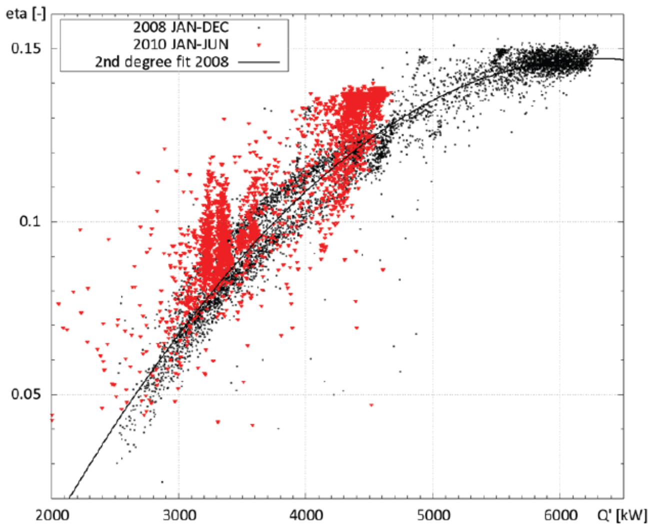


Figure 2. Electrical efficiency in function of the thermal input [9].

Through the analysis of the data material gathered during the operation of a 1 MWel and 5.3 MWth ORC plant located near Stuttgart, Germany a detailed analysis of the OR-Cycle data can be performed. The measurement results presented in figure 2 show that the installation achieves an electrical efficiency of 15% at nominal load, which is a relatively high value in comparison to water-steam plants in this power output range. However, a significant decrease of the electrical efficiency during part-load operation could be noticed.

ORC technology offers a solution for decentralized cogeneration based on biomass which can be characterized by relatively low investment and operational costs. However, the power-to-heat ratio of the ORC modules is notably lower in comparison to the biomass gasification. Therefore, gasification appears to be a better solution for combined heat and power generation. Nevertheless, one should be kept in mind that gasification plants require high quality fuel and significantly increased investment [8]. Although the installation rates of ORC plants are getting lower, the OR-Cycle still offers an interesting alternative for cogeneration systems that utilize solid biomass as the fuel.

1.2 Stirling engines

Stirling engines are indirectly heated gas engines operating by cyclic gas compression and expansion, with air, helium or hydrogen as the working medium. Stirling engines enable to generate energy in a closed cycle with the advantage that various heat sources can be used to power the system. The typical electrical capacities of Stirling plants range between 1 kW and 100 kW and the efficiency of power production is in the range of 15-30 per cent [11]. In comparison to the internal combustion engine Stirling engine can be characterized by relatively low maintenance requirements and favorable operating conditions. Although the Stirling process is already well known, practical experience from existing plants based on biomass combustion shows that there are still unsolved problems related to fast corrosion or fouling of the heat exchanger surface.

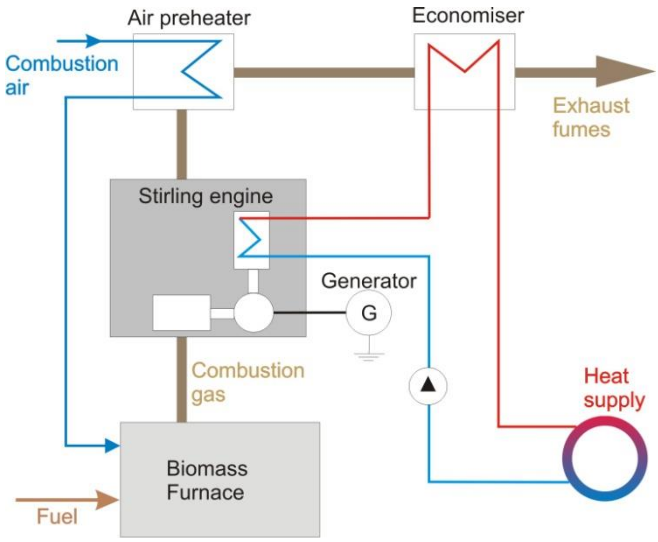


Figure 3. Biomass Stirling CHP system

The experience that has been gathered during the operation of a 74 kW_{el} Stirling-DK engine in Liebenau (Germany), which has been put into operation 2008 has shown that problems still occur due to changing fuel quality and reliability of the plant components. The fuel quality must be as good as possible in order to avoid problems with the plant operation and the combustion gases from the biomass furnace should be as clean as possible. Particles contained in the gases used for heating can form deposits on the heat exchanger surface which can negatively affect the process efficiency.

Due to the relatively low power output range and still unsolved technical problems the application of Stirling engines in biomass-fired plants is currently limited. Despite considerable research and development efforts, it was not possible to achieve the level of development which would enable a wide-spread application of Stirling engines [12].

2 BIOMASS GASIFICATION

Biomass gasification is applied for the conversion of biomass to syngas where the fuel is partially oxidized to a secondary energy carrier. The resulting gas mixture is called syngas or producer gas and consists of hydrogen, carbon monoxide, carbon dioxide and methane [13]. Syngas is currently in most cases used as a fuel for heat and power generation in highly efficient CHP systems. Syngas may also be used for the synthesis of several chemical products or it may be applied as base material for the production of biofuels.

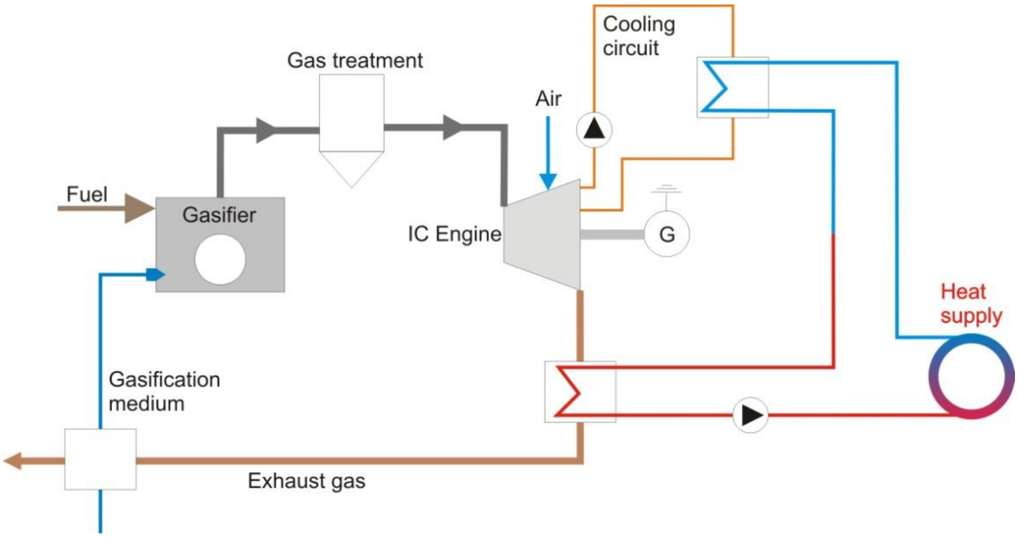


Figure 3. Working principle of a biomass gasification plant.

The main advantage of biomass gasification is the high power-to-heat ratio which enables a considerable reduction of pollutant emissions from power generation. Other advantages of biomass gasification are the multiple possibilities for the use of producer gas which can be applied for the production of heat, power and biofuels. The disadvantages of biomass gasification are the relatively high investment cost, problems with gas cleaning and the lack of long term practical experience of biomass gasification plants.

Biomass gasification plays a key role in the development of renewable energy generation in Germany and the amount of thermo-chemical gasification plants installed in Germany has grown rapidly in recent years. This is particularly due to the high electrical efficiency of gasification plants thus leading to higher revenue from electricity generation.

Biomass gasification is along with the water-steam power process and the ORC process one of the few proven technologies for heat and power generation from biomass fuels. The rising fuel prices and the good performance of gasification plants are the main reason for a rapid expanding use of this technology in Germany [14].

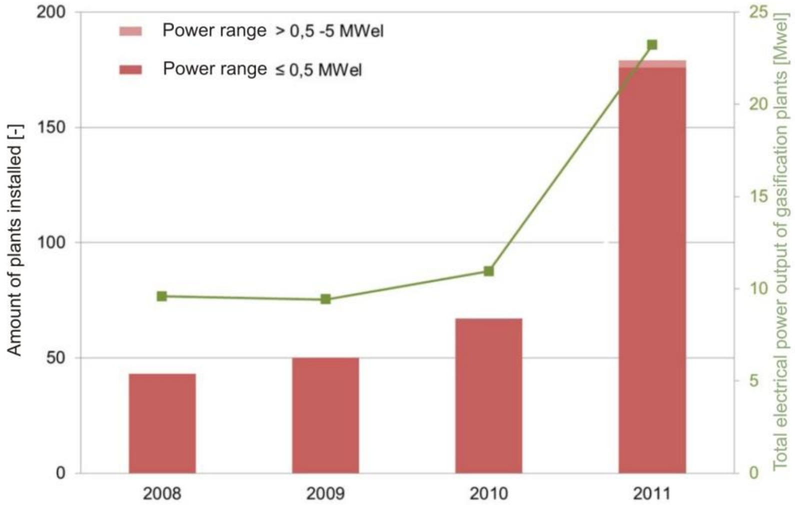


Figure 4. Development of the gasification based power generation from biomass in Germany [12].

Biomass is gasified either in small-scale plants with a power output below 50 kWel which are mainly used to cover the energy demand in agricultural and commercial sector. Gasification systems in the middle power range between 50 and 500 kW_{el} power output are operated mainly in heat driven mode in systems with relatively high heat demand. The development of plants in the highest power range of more than 500 kW_{el} is basically stagnating. This is due to the relatively high maintenance effort of large plants and the resulting low economical efficiency of large biomass gasification systems.

In conclusion it can be said that gasification plants offer the most developed and efficient systems for biomass based power generation in small-scale plants with a power output below 500 kW_{el}. Small-scale gasification plants seem to work reliable as some of them achieve more than 7000 full load hours. However, there are still areas of uncertainty concerning mainly the lack of long-term experience of biomass gasification. In comparison to small-scale systems large biomass gasification plants can be characterized by relatively high operational and maintenance costs, which are in the worst case leading to the insolvency of plant operating companies. Nevertheless, due to the high power-to-heat ratio gasification is a very promising alternative for biomass based cogeneration.

3 BIOMASS PYROLYSIS

The pyrolisis of biomass is a thermal treatment at a temperature of approx. 500°C which results in a production of liquid products that can be used as secondary energy carrier or as chemical products. The main advantage of pyrolisis is the possibility of generation of liquid energy resources that can be used in fuel oil burners and diesel engines. Pyrolisis of biomass can be defined as a process by which the biomass is converted into liquid fuels, pyrolisis-gas and biochar in the absence of oxygen. In contrast to the gasification where syngas and ash are the main products, the technology of biomass pyrolisis is used for the production of liquid and solid energy resources. Pyrolisis processes can be categorized as slow and fast pyrolisis.

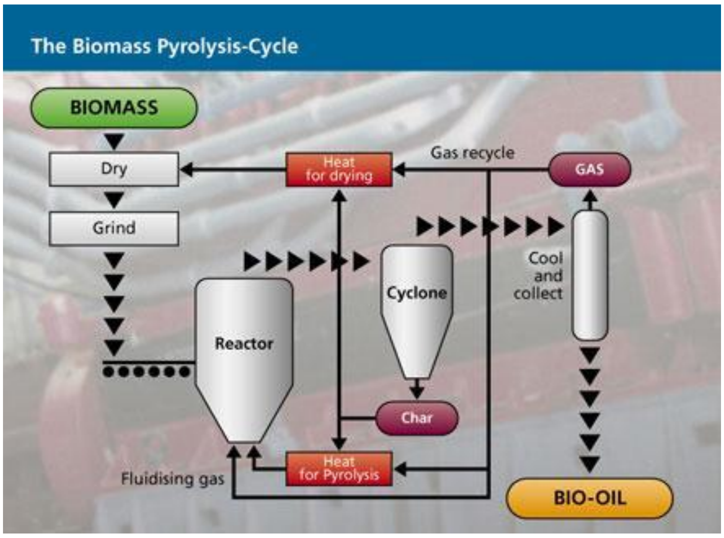


Figure 5. Pyrolisis process of biomass [15].

The process of fast pyrolisis occurs at moderate temperatures and short residence time of water vapor which are optimal conditions for the production of liquid fuels. In the fast pyrolisis the thermo-chemical decomposition of biomass occurs very quickly to generate mostly vapors and aerosols as well as some gas and charcoal. After the reaction products condensate, a dark brown liquid called bio-oil is formed which has a heating value of about half that of conventional fuel oil [16][17]. Slow pyrolisis is defined as thermal decomposition of biomass which occurs under a slow heating rate. Conventional pyrolisis is mainly applied in order to achieve high charcoal continent of reaction products [18]. The fast pyrolisis is the preferred technology for the thermo-chemical processing of biomass because solid biomass and wastes can be rapidly converted into liquid products.

Biomass pyrolisis is attractive because it provides an opportunity to convert biomass and wastes into clean energy. However, biomass pyrolisis plants are still in the development or demonstration stages in Germany. A pilot plant for the pyrolisis of straw for the production of bio-oil was developed at the Karlsruhe Institute of Technology. The University of Rostock developed a micro-turbine for the generation of power from bio-oil. The technology of pyrolisis is now at the beginning of the implementation oriented stage of research.

4 ANAEROBIC DIGESTION

Biogas is produced in a biological decomposition of biomass in the absence of oxygen; where organic matter is broken down to form a gas mixture called biogas. The goal of anaerobic digestion is the conversion of organic substrates by different microorganism to biogas, which can be applied as a secondary energy carrier. Anaerobic digestion process produce a gas mixture which consists mainly of methane (50-75 vol.%) and carbon dioxide (25-50 vol.%) as well as small quantities of hydrogen, hydrogen sulphide, ammonia and other trace gases [19].

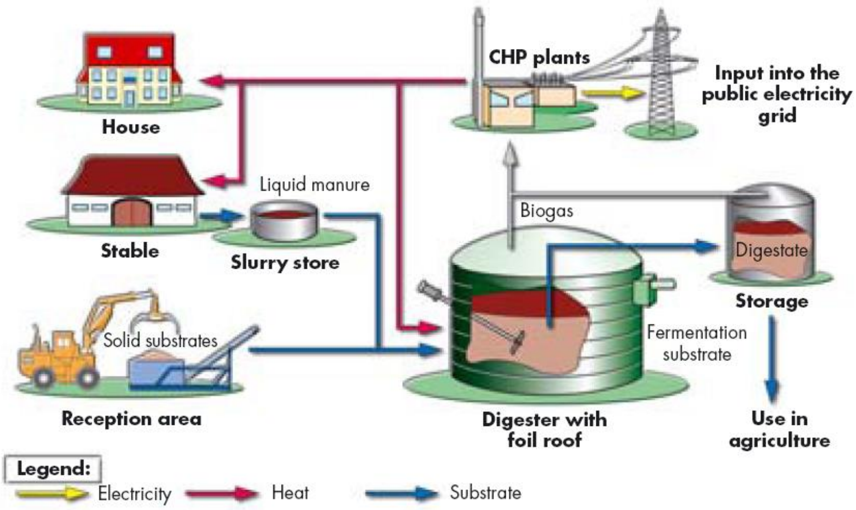


Figure 6. Working principle of a biomass gasification plant [20].

The production of biogas is considered to be a promising alternative for electricity generation from biomass in decentralized CHP plants which operate on farms. Due to their several advantages biogas systems are widely employed in Germany. Aside from the production of heat and electricity, biogas systems offer a possibility to reduce manure volume, produce a nutrient reach effluent and reduce methane emissions, which has a global warming potential of 21 times that of carbon dioxide [21]. Figure 6 shows the mode of operation of an anaerobic digestion system which was engineered to optimize the production of biogas.

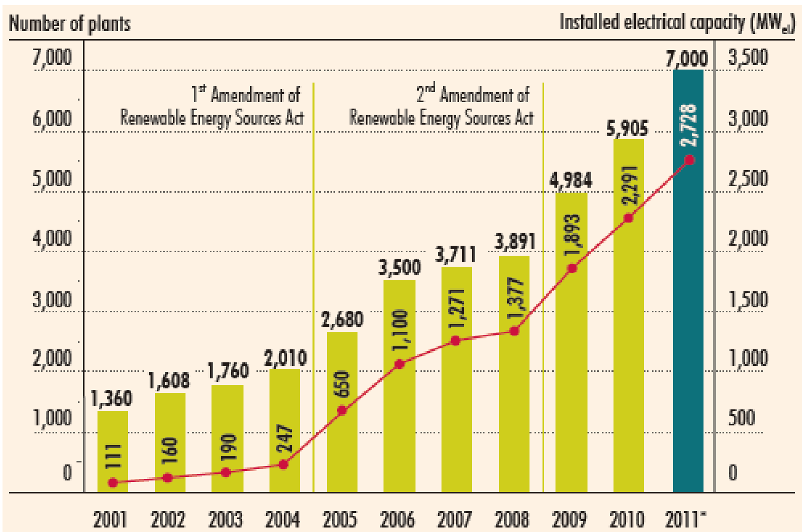


Figure 7. Development of biomass plants in Germany [22].

Germany is currently the world leader in the production and utilization of biogas, especially for the generation of electricity. In the last decade the number of plants increased from 1.360 in 2001 to 7.000 in 2011 and the installed capacity also increased from 1.360 MW_{el} in 2001 to 2.728 MW_{el} in 2011. This is mainly due to the implementation of the Renewable Sources Act (EEG) which resulted in a sharply increase in the amount of produced biogas. Under the EEG there is a payment for supply of energy from renewable sources which made the generation of biogas an economically attractive alternative for the conversion of biomass to energy. The support of biogas production and utilization offered by the EEG in 2004 and continued in 2009 has given rise to the creation of a considerable number of biogas system producers and equipment suppliers, which has enabled Germany to become a market leader in the field of planning and construction of biogas plants [19][23].

Biogas is mainly used as secondary fuel for combined heat and power generation and in systems that enable injection of biomethane (upgraded biogas) into the gas grid. According to the energy policy goals defined in the amendment of EEG in 2009 upgrading of biogas to natural gas quality and generation of electricity from biogas after transmission through the natural gas grid will play a key role within the national energy policy. Although there is a potential to improve the system components and plant efficiency, biogas production and utilization is a promising alternative for renewable energy deployment in Germany. Considering the fact that only about 10% of the total available potential for biogas generation is currently used it can be expected that the biogas sector in Germany will continue to expand strongly in the future.

5 BIODIESEL PRODUCTION

The limited potential of fossil fuels necessitates consideration of alternative fuels from renewable sources. Biofuels can be used in a short time to replace petrol and diesel in conventional driving concepts. The term biofuels describes biomass based fuels which include bioethanol, biomethanol, biodiesel and hydrogen. Biodiesel is the mainly used and widespread biogenic fuel in Germany. Biodiesel is a vegetable oil methyl ester which can be used as fuel for diesel engines. Biodiesel is produced by chemical reaction of vegetable oil or animal fat with an alcohol. Biodiesel is a promising alternative to conventional diesel fuel because it can be pumped, stored and handled using the existing devices for mineral oil based fuels. Biodiesel is an attractive alternative for classical driving concepts, because it is environmentally friendly and can be synthesized from edible and non-edible oils. The substrates for the production of biodiesel are non-toxic, biodegradable, renewable sources. The disadvantages of the production of biodiesel are however, the relatively high energy demand of the biodiesel generation process and the formation of glycerin as by-product in biorefineries [24][25][26].

The raw materials that are currently used in the German biofuels sector for the production of biodiesel are above all rapeseed oil, soybean oil and palm oil as well as animal fats and used cooking oils/fats. The production capacities for biodiesel are constantly being extended and increased from 0.35 million tons per year in 2000 to currently approximately 4.7 million tons per year. The current utilization rate of German production capacities for biodiesel is at about 70%. The reasons for the incomplete production capacity utilization are the relatively low demand and cheap fuel imports, especially of subsidized US biodiesel.

Table 1: Production, capacity and utilization of biodiesel in Germany.

Year	Production million tons/year	Capacity million tons/year	Fuel consumption million tons/year
2007	2.92	4.75	3.25
2008	2.5	4.83	2.67
2009	2.42	4.83	2.5
2010	3.08	4.83	2.58
2011	2.38	4.71	2.42

Due to the political framework conditions the German biofuel sector is dominated by biodiesel. The blending market became very important in the biofuels supply chain, which enabled the oil industry to act as a key player within the German biofuel sector. Blending biodiesel into conventional diesel fuel is a promising alternative to reduce the dependency of the transport sector from fossil fuels. However, the relatively low prices of petroleum-based fuels reduce the utilization of biodiesel which is currently more expensive. But there is still a lot of uncertainty concerning petroleum reserves and further development of mineral oil prices which makes the utilization of biodiesel an essential alternative for the future of German transport sector.

6 BIOETHANOL PRODUCTION

Bioethanol is produced by the fermentation of sugars from sugar-containing plants (sugar beet, sugar cane) or starch-containing plants (potatoes, corn, grain). The sugar contained in plants is converted during fermentation by yeast and enzymes to ethanol and CO_2. The alcohol fermentation is the most well known and widely used technical process for the production of bioethanol. Although the energy balance of bioethanol production is positive and the fuel can be used to improve the quality of petrol there are also disadvantages of utilization of bioethanol as fuel for petrol engines. The disadvantage of bioethanol is mainly related to the highly hygroscopic and corrosive properties of the fuel which can lead to damage of engine parts [27].

Since 2005 the production facilities for bioethanol in Germany enable the generation of this fuel on an industrial scale. The production capacity for bioethanol are constantly extended and increased in the last years from 0.48 million tons in 2005 to approximately 1 million tons in 2011. The current utilization rate of production capacities is at approximately 60%. The incomplete capacity utilization is caused by relatively low demand for biofuels and the relatively low imported fuel price [28].

Table 2: Production, capacity and utilization of bioethanol in Germany.

Year	**Production million tons/year**	**Capacity million tons/year**	**Fuel consumption million tons/year**
2007	0.3	0.58	0.46
2008	0.45	0.83	0.63
2009	0.58	0.88	0.88
2010	0.61	0.92	1.04
2011	0.67	0.93	1.21

Bioethanol can be efficiently used as alternative for petrol as it is similar in many of its parameters and can be therefore used as fuel in highly-developed combustion engines with relatively simple modifications. However, the traditional technological production path based on fermentation can substitute only a part of mineral fuels. The additional part of fuel demand can be covered by bioethanol produced from cellulosic material. The substrates used for bioethanol production from cellulosic material are mainly wood, grass and non edible parts of various plants, whereby the fuel is produced from carbohydrates located in the plant cell walls.

7 CONCLUSIONS

Biomass can be converted into useful forms of energy via a number of methods. The processes applied to generate energy from biomass can be divided into two main categories: thermo-chemical and biological conversion routes. There are several thermo-chemical conversion processes of biomass such as combustion, gasification and pyrolisis. Among the thermo-chemical conversion routes of biomass, combustion is the most mature and widespread method for energy generation from biomass. Decentralized ORC cogeneration plants based on biomass combustion are a promising alternative for energy generation from biomass, as they combine considerable high conversion efficiencies with reasonable fuel transport distances. Biomass-fired ORC plants are available in a size range from 200 kW_{el} up to 3100 kW_{el}. ORC technology offers a commercially available solution for decentralized cogeneration based on biomass which can be efficiently applied in the middle-size range below the power range of classical steam power plants.

While biomass pyrolisis plants are still in the development phase, biomass gasification is a very promising alternative for small-scale (< 500 kW_{el}) cogeneration plants based on biomass. The main advantage of small-scale gasification plants is their high power-to-heat ratio which leads to higher revenue from electricity generation. The high electrical efficiency of gasification plants and the rising fuel prices are the main reasons for a rapidly growing amount of gasification plants installed in

Germany.

Biological conversion processes of biomass are utilized for the production of biogas and biofuels. Production and utilization of biogas plays currently a key role in the German renewable energy sector. Germany has become the world leader in the production and utilization of biogas, especially for the generation of electricity. Due to the fact, that only approximately 10% of the total available potential for biogas generation is currently used, it can be expected that the amount of biogas produced will continue to increase in the future.

Biofuels play also an important role within the German energy market mainly because biofuels are renewable, domestic resource and can be characterized by an environmentally friendly emission profile. The utilization of biofuels and the production capacities have grown significantly during the last years. However, due to relatively high production cost and cheap fuel imports the capacities for biofuels production have not been completely utilized yet. But taking into account the limited potential of fossil fuels there is a reserved interest in biofuels for the transport sector in Germany.

8 REFERENCES

[1] Van Loo S., K. J. (2008). The Handbook of Biomass Combustion and Co-firing. London: Earthscan.

[2] Obernberger, I. (2009). Reached Development of Biomass Combustion Technologies and Future Outlook. In proceedings of 17th European Biomass Conference, Hamburg pp. 20-37.

[3] Nussbaumer, T. (2003). Combustion and Co-combustion of biomass: Fundamentals, Technologies, and Primary Measures for Emission Reduction. *Energy and Fuels (17) 2003* , S. 1510-1521.

[4] Swithenbank, J., Chen, Q., Zhang, X., Sharifi, V., & Pourkashanian, M. ((35) 2011). Wood will burn. Biomass And Bioenergy , S. 999-1007.

[5] Strzalka, R., Ulbrich, R., & Eicker, U. (2010). Analysis of biomass ORC plant connected to district heating network. In proceedings of 18th European Biomass Conference, Lyon, pp. 1347-1351.

[6] Zahoransky, R. A. (2009). Energetics - systems for energy conversion (in German). Wiesbaden: Vieweg + Tuebner.

[7] Strzalka, R., Ulbrich, R., Eicker, U., & Duminil, E. (2009). Analysis of a biomass tri-generation system in an urban area. In proceedings of 17th European Biomass Conference, Hamburg pp. 2167-2171.

[8] Rentizelas, A., Karellas, S., Kakaras, E., & Tatsiopoulos, I. (2009). Comparative techno-economic analysis of ORC and gasification for bioenergy applications. *Energy Conversion and Management (50)* , pp. 674-681.

[9] Erhart, T., Eicker, U., & Infield, D. (2011). Part-load characteristics of Organic-Rankine-Cycles. In proceedings of the 2nd European Conference of Polygeneration, Tarragona, pp. 1-11.

[10] Maraver, D., Sin, A., Royo, J., & Sebastian, F. (2013). Assesment of CCHP systems based on biomass combustion for small-scale applications through a review of the technology and analysis of energy efficiency parameters. Applied Energy (102) , S. 1303-1313.

[11] Kaltschmitt, M., Hartmann, H., & Hofbauer, H. (2009). Bioenergy – fundamentals, technology and process engienering (in German). Berlin-Heidelberg: Springer Verlag.

[12] DBFZ. (2012). Monitoring of the Impact of the EEG directive on the electricity generation from biomass – final report for the period 2009-2011 (in German). Berlin: BMU.

[13] Balat, M., Balat, M., Kirtay, E., & Balat, H. (2009). Main routes for the thermo-conversion of biomass into fuels and chemicals. Part 2: Gasification systems. *Energy Conversion and Management (50)* , pp. 3158-3168.

[14] FNR (2005). Road map bioenergy: planing, operation and economic efficiency of biomass based systems (in German). Gülzov: FNR.

[15] International Energy Agency (2007). Bioenergy Project Development & Biomass Supply. Paris. IEA.

[16] Bridgwater, A. (2012). Review of fast pyrolysis of biomass and product upgrading. Biomass and Bioenergy (38) , pp. 68-94.

[17] Wright, M., Daugaard, D., Satrio, J., & Brown, R. (2010). Techno-economic analysis of biomass fast pyrolysis to transportation fuels. Fuel (89) , pp. 2-10.

[18] Balat, M., Balat, M., Kirtay, E., & Balat, H. (2009). Main routes for the thermo-conversion of biomass into fuels and chemicals. Part1: Pyrolysis systems. Energy Conversion and Management (50) , pp. 3147-3157.

[19] FNR. (2010). *Guide to Biogas - From production to use.* Gülzow: FNR.

[20] FNR. (2009). *Bioenergy.* Gülzow: FNR.

[21] White, A. J., Kirk, D. W., & Graydon, J. (2011). Analysis of small-scale biogas utilisation in Ontario cattle farms. *Renewable Energy (36)* , pp. 1019-1025.

[22] FNR;. (2012). *Bioenergy in Germany: Facts and Figures.* Gülzow: FNR.

[23] Poeschl, M., Shane, W., & Owende, P. (2010). Prospects for expanded utilization of biogas in

Germany. *Renewable and Sustainable Energy Reviews (14)* , pp. 1782-1797.

[24] Yusuf, N. N., Kamarudin, S. K., & Yaakub, Z. (2011). Overview on the current trends in biodiesel production. *Energy Conversion and Management (52)* , pp. 2741-2751.

[25] Eevera, T., Rajendran, K., & Saradha, S. (2009). Biodiesel production process optimisation and characterisation to assesss the suitability of the product for varied environmental conditions. Renewable Energy (34) , pp. 762-765.

[26] Bozbas, K. (2008). Biodiesel as an alternative motor fuel: Production and Policies in the European Union. Renewable and Sustainable Energy Reviews (12) , pp. 542-552.

[27] FNR. (2006). *Biofuels.* Gülzow: FNR.

[28] DBFZ. (2012). *DBFZ Report Nr. 11 – Monitoring of the biofuel sector in Germany (in German).* Leipzig: DBFZ.

DEVELOPMENT OF INTERNATIONAL PELLET MARKETS UP TO 2025, AND BEYOND

Andreas Teir, Director, Pöyry Management Consulting
Pöyry Management Consulting Oy, Jaakonkatu 3, FI-01621 Vantaa, Finland
+358 10 33 22840, andreas.teir@poyry.com

<u>Background:</u>

The total global consumption of wood pellets is estimated at approximately 20 million tonnes for the year 2012. Today, international pellet trade flows are directed mainly towards Western Europe following demand for industrial pellets for power and heat. Recent policy changes in a number of European countries will result in an unprecedented demand increase of industrial pellets. In the United Kingdom, several coal-fired power plants will convert to using 100% biomass. This will result in a rapid demand peak for wood pellets in a very short time frame.

Furthermore, technology development for the production of black pellets is in an intensive phase and on the brink to commercialisation. Black pellets with its coal-like characteristics, when commercially available on the market, will have a tremendous market penetration potential for co-firing purposes. Black pellet production technologies are expected to deliver efficiency gains and contribute to overall supply chain cost savings, compared to standard biomass pellets.

<u>Purpose of the work</u>:

Pöyry has since 2009 provided the global pellet industry with insights in the emerging pellet market development. Pöyry's global pellet market research and analysis to be completed in June 2013, is a continuum on offering the industry with a comprehensive and thorough view on the market development in the medium and longer term.

<u>Approach:</u>

Pöyry is a global engineering and consulting firm, and is consistently delivering due diligence, feasibility, strategy consulting and engineering projects with leading industry clients – focusing on sustainability and the optimisation of all supply chain steps from production through to trade, refinement, conversion and recycling of products and by-products – and has gained detailed industry insight. Pöyry's next global pellet market research and analysis will be completed in June 2013. This global pellet market analysis, which has become a key reference in the industry, is performed through the firm's proprietary facility and resource databases, market insight and official trade statistics.

<u>Results and conclusions:</u>

Pöyry's next global pellet market research and analysis in 2013 is yet to be completed. The report once completed will address key market development trends, drivers and inhibitors including: forecast for global pellet market demand and production by region up to 2025, market economics and market price scenarios for industrial pellets, sustainability developments, including discussion of ILUC and carbon debt and potential impact on markets, and the technology development and expected role of black pellets in the global pellet markets. The results of the research will be important for industry participants who benefit from a deep understanding of the pellet market dynamics.

PÖYRY
Engineering balanced sustainability™

DEVELOPMENT OF PELLET MANUFACTURING AND BIOMASS USE IN AUSTRALIA

Andrew Lang

Bioenergy makes up about 75% of all primary energy from renewable sources in Australia. But this is mostly as heat energy and particularly as household space heating using firewood. While the renewable energy sources contribute about 9% to Australia's electricity this is mostly from hydro and secondarily from wind, and the contribution from biomass is less than 1% (2500 GWh in 2011). The breakdown as of 2011 in renewable electricity capacity was as

	Installed capacity MW	Approx capacity factor %
Hydro	8501	30-50
Wind	2175	30
Bioenergy	773	85
Solar PV	1041	15-20

While there has been enthusiastic government support for wind and solar PV and investment in these has responded to various subsidy inducements, investment into larger scale industrial bioenergy projects has lagged. The main technologies producing electricity from biomass are as co-generation using bagasse (61%), black liquor (10%) and as electricity only from sewage gas (6%) and landfill gas (21%).

However there is real potential for a radical expansion of bioenergy. Australia has 50 million tonnes, and potentially up to 100 million tones a year, of economically-available biomass. By use of mature CHP technologies such as 25-50 MW-e capacity CHP plants in regions close to biomass supply this biomass could produce up to 5500 MW-e/year, or 20% of Australia's current base electricity needs of about 29,000 MW/year. The heat and transport biofuels produced from anaerobic digestion of putresible wastes, from smaller regional biomass volumes and from chip and pellets for small to medium scale plants supplying heat to industry and institutions would mean that 20% or more of Australia's primary energy could be supplied from existing economically available biomass. While existing policies at state and federal levels do not support this some changes are occurring in this scene.

As elsewhere, Australian biomass is principally of four types

1.	Agricultural and horticultural wastes and residues – straw, bagasse, grape marc, olive industry by product.	40-60 million t
2.	Wood and timber industry byproduct and residues	10-15 million t
3.	Municipal solid wastes (60-70% biomass)	15-20 million t
4.	Putrescible wastes (10% DM)	20 million m3

Expansion of plantation forestry, and of short rotation coppice energy crops (including oil mallee) will produce further significant amounts of biomass in response to local, regional or national market signals. There is obvious potential for 5-10 million ha to be replanted across the 100 million ha of more productive land over-cleared during the expansion of farming since the 1850s, and particularly after the 1940s.

At the same time there is a renewed commitment to production of domestic quality pellets with up to 100,000 tonnes of capacity installed or being planned by mid-2013. Prior to this the small level of production of quality pellets had to be supplemented by import from New Zealand, and the resulting high prices meant pellet stoves were only for the few innovators.

By end of 2011 there were 136 biomass-fuelled electricity generating plants of a minimum 100 kW-e in operation, and another 14 were in planning. While some CHP plants are in the order of 24 -60 MW-e these are in the bagasse and black liquor-fuelled CHP plants. In other industries and for landfill and sewage gas sources the capacity range tends to be 0.5-10 MW-e.

As Australian industries and local government have distanced themselves from the investment uncertainty dating from the GFC (when 3 woody biomass-fuelled CHP plants of about 30 MW-e each lost funding before construction started) there have been many small to medium bioenergy plants put back into planning or constructed. These include biomass to heat, and co-gen plants using agricultural and industry residues (including putrescibles wastes).

New bioenergy and bio-electricity capacity installed over the previous five years include a number of novel (for Australia) technologies –

- Upgrade and modernising of bagasse-fuelled cogeneration,
- BFB biomass/waste fuelled plants in recycled paper and cardboard production
- BFB CHP plant in instant coffee production using coffee grounds
- Woodchip fired heating systems from 1-6 MW-th for greenhouses and plant nurseries
- Sawdust-fuelled 600 kW-th heating plant for swimming pool heating.
- ORC turbines using sawmill processing wastes

During 2013 construction has been underway on some plants using other novel (for Australia) technologies or biomass fuels. These include

- Gasification of municipal wastes to provide electricity
- ORC turbines using heat from boilers fuelled by grape marc
- Pilot plants for producing cellulosic ethanol and algal biodiesel
- A chip-fuelled Austrian 100 kW-th boiler to heat a rural hospital

And advanced funding and planning approvals are in place for plants converting –

- Straw to electricity
- Sweet sorghum to ethanol
- Green waste to heat, electricity and biochar by slow pyrolysis

However it is clear that the sector is still being held back. There are a number of obvious causes.

- Ignorance and lack of clear policy at state and federal level – including uncertainty about he future of carbon pricing
- A shortage of really competent consultants who are across the technologies and economics
- General ignorance and misinformation among the general public
- A very limited number of agencies able to supply and maintain or service imported plant and equipment. Most small systems are either imported via New Zealand, or come in as a once-off item.
- Minimal production of domestic pellets – 10-20,000 tonne capacity in 2013.
- Zero current production of industrial pellets
- Very few mobile machines for energy wood harvesting, infield chipping or chip transport.

On the plus side there is strong interest among industry and local government and some waste and water/sewage management agencies. Information is gradually spreading (despite the lack of formal government support for the sector) and as new installations serve as demonstration sites to show the practicality and economics of bioenergy technologies. Also for the present there are very substantial amounts of funding or soft loans in place for such innovative applications of 'new' (for Australia) renewable energy technologies.

The push continues to inform all industries which generate large volumes of biomass – almond shells, olive pits, cotton seed and husks, plantation residues, green waste and manures – about the availability of proven technologies that suit these feedstocks and can produce the desired products.
At the same time the cost to industries of the conventional energy carriers of natural gas, LPG, diesel fuel, and electricity, is on the rise. With a return to some sensible tax on carbon the cost of brown and black coal will also increase to levels that will stimulate an economic review of energy inputs for organisations like laundries, brickworks and food processing industries.
Overall it is likely that in Australia we are 'over the hump' – both economically and politically - and that adoption of bioenergy technologies and better utilisation of economically available biomass will have become the norm by 2020.

CRUDE TALL OIL BASED RENEWABLE DIESEL AS A BLENDING COMPONENT

Ville Vauhkonen[1], Sari Mannonen[2], Seppo Niemi[3]
[1]UPM-Kymmene Corporation, Biofuels R&D, Paloasemantie 19, FI-53200 Lappeenranta, Finland, Tel: +358-40-1679052, ville.vauhkonen@upm.com
[2]UPM-Kymmene Corporation, UPM Biofuels, Eteläesplanadi 2, FI-00101 Helsinki, Finland, Tel:+358-45-2651345, sari.mannonen@upm.com
[3]University of Vaasa, PO Box 700, FI-65101 Vaasa, Finland, Tel: +358-29-4498304, seniemi@uva.fi

SUMMARY

UPM aims to become a major player in Europe in the production of renewable biofuels. The first biofuel investment decision was made on a biorefinery to Lappeenranta, Finland. Construction has begun and will be completed in 2014.

The fuel production is based on using crude tall oil (CTO), a wood based residue of pulping process, as a raw material for the production. The biorefinery is based on hydrogenation process, the main product being renewable diesel. In addition, a fraction of renewable naphtha is produced. CTO is in-edible oil that is a mixture of; fatty acids (40-50%), resin acids (30-40%), neutral substances and impurities. Using CTO to produce high quality second generation biofuels is an innovative way to use a residue of existing industry without changing and/or compromising the main processes of the pulp mill. The production process for hydrogenation of CTO to biofuels has been developed in-house.

The renewable diesel product properties are mostly comparable to EN590 diesel fuel. The main differences are; low aromatic content, low sulphur content and higher cetane number. The renewable diesel can be used as blending component with all blend ratios without compromising the engine operability. The engine test results presented in this paper show that when using UPM's renewable diesel as a blending component (30%) there is a clear decrease of emissions (gaseous and particle).

UPM also plans to build a biomass-to-liquid (BTL) biorefinery. The European Commission awarded UPM a grant of EUR 170 million for solid wood-based biorefinery project in Strasbourg, France. It will utilize wood residues, such as logging residue or bark as raw material and the main product will be renewable diesel.

PURPOSE OF THE WORK & APPROACH

CTO-based renewable diesel characteristics were compared to those of the traditional oil-based diesel fuels. CTO was hydrotreated, the product collected, fractionated into diesel and naphtha fractions, and analyzed. The tests were performed with a 30% blend with regular pump station EN590 diesel sold in Finland. The tests were conducted using a non-road AGCO Power CTA 44 heavy duty diesel engine.

SCIENTIFIC INNOVATION AND RELEVANCE

UPM has developed an innovative production process from CTO to pure renewable diesel, performed and controlled at the same biorefinery site. The product's characteristics correspond to those of the traditional fuels highly complementing today's vehicles, and the GHG emissions are reduced significantly. UPM is building the hydrogenation biorefinery in Lappeenranta, Finland. The industrial scale investment is the first of its kind globally. The biorefinery will produce annually 100,000 tons of renewable diesel for transport. The annual production will contribute one fourth of Finland's biofuel target in transportation fuels if sold entirely on the domestic market. UPM's biofuels exceed the current and tightening sustainability requirements set by both the EU and Finland.

RESULTS

CTO-based renewable diesel is a high quality fuel with some properties that differ from those in EN590 fuel standards (e.g. cetane number). The engine tests performed showed clearly that the high blend ratio (30%) did not compromise the fuel properties or the engine functionality. In addition, the engine emissions were decreased when using renewable diesel as a blending component.

CONCLUSIONS

Converting CTO to biofuel is an innovative way to use that residue without changing the main process, pulp and paper production. The key success factor of the novel drop-in fuel is sustainability: feedstock is wood-based, non-food origin with no indirect land use change, and the GHG emission reduction is significant. Therefore, it fulfills the requirements set for renewable biofuels. UPM utilizes its own development work and produces a cost-competitive high quality transport fuel fully compatible with today's vehicles and fuel distribution systems. The Lappeenranta biorefinery investment is the first step for UPM in becoming the leading producer of wood-based advanced biofuels. In addition to Lappeenranta Biorefinery, UPM is planning to produce renewable diesel from solid wood raw materials. The raw materials to be used in the production of UPM’s diesel would mainly consist of sustainably sourced wood biomass, such as logging residues and bark. UPM will not use raw materials suitable for food.

BIOMASS SUSTAINABILITY ASPECTS

GHG EMISSIONS OF FOREST-BIOMASS SUPPLY AND USE IN FINLAND

*Jäppinen, Eero*1, Korpinen, Olli-Jussi1, Laitila, Juha2 & Ranta, Tapio1*
1 Lappeenranta University of Technology, Sammonkatu 12, 50130 Mikkeli, Finland
2 Finnish Forest Research Institute, Joensuu, Finland
* Author for all correspondence
tel: +358 50 5844634, e-mail: eero.jappinen@lut.fi

Purpose of the work: The purpose of the work is (1) to assess and summarize the effect of local conditions regarding biomass availability and supply chain on the greenhouse gas (GHG) emissions of forest biomass supply, (2) assess emissions deriving from each stage of forest bioenergy supply chain by reviewing current research and literature, and (3) assess the net reductions of GHG emissions achieved with different forest biomass energy utilization schemes in respect to the current situation in Finland and EU's sustainability criteria.

Approach: Life cycle assessment (LCA) methods are used to assess the GHG emissions of bioenergy use and production, including all steps of the production, conversion and utilization chain. The GHG emissions are compared to the actual reference systems in Finland as well as EU's fossil comparator values. When possible, emissions dependent on the geographical location were assessed separately for Southern Finland and Northern Finland. Geographical information system methods were used for assessment of forest and transportation operations. Two traditional bioenergy schemes are assessed (combined heat and power (CHP) and condensing power) as well as three alternative options, which would enable replacement of fossil energy production in Finland on a short- to medium term (torrefied pellets, gasification and pyrolysis oil). The forest-biomass feedstock categories considered for this study include harvesting residues from final fellings (HR), spruce (Picea abies) stumps from clearcuts (ST), and small-diameter energy wood from early thinning or first thinning (EW).

Scientific innovation and relevance: LCA provides a way of assessing the GHG performance of a given energy scheme in a case dependent matter, but the results depend on input parameter values, system boundaries, allocation procedures, and fossil reference system, and many key parameters vary between different systems and locations. Forest biomass from natural forests represents a geographically distributed feedstock, and geographical location affects the results of a forest bioenergy LCA in several ways. For example, raw material availability, forest operations, transportation possibilities, biomass end use, fossil reference systems and forest carbon balances are all to some extent dependent on the geographical location. This work assesses biomass supply chains in Finnish context and links the supply chain emissions with end use possibilities. The work provides an answer to the following questions: (1) What are the GHG emissions of bioenergy production and use?, (2) How should a given resource be used in terms of GHG mitigation? ,and (3) How much GHG emissions can be saved through different bioenergy schemes in Finland?

Results: (1) The GHG emissions of the feedstock supply chains are presented, (2) possible GHG savings in Finnish conditions are presented and (3) GHG savings in respect to EU's fossil comparator values and EU's sustainability criteria are presented.

Conclusions: (1) The most important aspects of forest bioenergy supply and production chains in terms of GHG emissions are summarized, and (2) the GHG performance and possible fulfillment of current and future EU sustainability criteria is assessed of for each bioenergy scheme, also in terms of geographical location and feedstock used.

SUSTAINABILITY OF BIOMASS FOR ENERGY ON EUROPEAN LEVEL

Kjell Andersson
Information Secretary
SVEBIO – Swedish Bioenergy Association
Holländargatan 17, SE-11160 Stockholm, Sweden
Kjell.andersson@svebio.se

Abstract

Sustainability issues concerning biomass have been in the focus on EU level for the last five years. For liquid biofuels and bioliquids most of the sustainability issues were regulated in the Renewable Energy Directive in 2009, although some issues are still to be decided. The debate has been intense on ILUC (indirect land use change) and "food versus fuel", and a proposal from the Commission is now on the table on these issues. For solid biofuels (biomass) for heat and electricity the Commission has yet to come up with a proposal. In February 2011, the Commission presented a report but did not propose common binding criteria for EU. A new report and proposal has been expected for some time, but has been delayed due to internal disagreements within the Commission and between the member states.

Environmental NGO:s, some scientific institutions, and media today question the sustainability of biomass for energy, to a degree that may drastically hamper the development of the business and slow down investments. Even the basic assumptions of biomass as a renewable and carbon neutral energy source are being cast in doubt. The response from the industry has been to engage in voluntary certification and to develop regional and global standards.

The outcome of negotiations on EU level will be crucial to the development of trade with and utilisation of biomass for energy in Europe. It is essential that regulations do not include overly bureaucratic and costly systems for control and compliance. Yet common criteria may pave the way for more trade.

EFFECTIVENESS OF BIOENERGY SUSTAINABILITY CRITERIA AND LAND USE POLICIES TO CONTROL FUTURE GHG EMISSIONS FROM BIOENERGY PRODUCTION

Stefan Frank (corresponding author) - International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, Tel.: + 43 2236 807 218, E-mail: frank@iiasa.ac.at
Hannes Böttcher IIASA, Laxenburg, Austria, bottcher@iiasa.ac.at
Petr Havlík - IIASA, Laxenburg, Austria, havlikpt@iiasa.ac.at
Berien Elbersen - Alterra Wageningen UR, Wageningen, Netherlands, berien.elbersen@wur.nl

PURPOSE OF THE WORK

The EU Renewable Energy Directive (RED) targets, implemented to achieve climate change mitigation, affect the level of agricultural production in the EU and in the rest of the world. This article presents an impact assessment of increased biomass supply under different sustainability constraints on land use and resulting total GHG emissions at global and EU level.

APPROACH

We apply GLOBIOM, a global partial equilibrium model integrating the agricultural, livestock, bioenergy and forestry sector based on geographically explicit modeling of supply under prescribed demand. By simulating the competition between major land-based sectors, the model estimates emission reductions and increases in each sector. We run different simulations to estimate how effects could change total GHG emissions under different scenarios.

SCIENTIFIC INNOVATION AND RELEVANCE

Various studies have analyzed effects of bioenergy use on land use change and GHG emissions in global general or partial equilibrium models. They indicate that in addition to biofuel specific sustainability criteria stringent land use policies need to be established to avoid GHG emissions but also loss of biodiversity and habitat. Here we use such a model and provide an assessment of impacts of specific EU bioenergy and climate change mitigation policies on total GHG emissions related to bioenergy production in and outside the EU. The high degree of integration of different land uses enables us to assess effects of certain policies on all kinds of land uses and associated impacts on the environment.

RESULTS

According to the model, global GHG emissions from agriculture and land use change are anticipated to rise significantly up to 2030 due to various drivers (among others: GDP and population, diet shifts and also bioenergy demand) despite basic sustainability criteria implemented by the RED (Reference scenario). Applying additional criteria, mainly protecting biodiversity outside the EU, overall GHG emissions can be reduced by 5% in 2030 compared to the Reference. Deforestation area decreases in this scenario slightly due to exclusion of high biodiversity forests but also due to increasing demand for energy wood that makes forests more valuable. If, however, in addition deforestation is prevented through effective land use policies, global GHG emissions can be reduced by 20% (compared to the Reference scenario).

CONCLUSIONS

We conclude that sustainability criteria to biofuel production and imports do not mitigate potential negative impacts on total GHG emissions effectively. Unsustainable biomass production in sectors not covered by the bioenergy criteria can be best avoided by targeting deforestation and biodiversity loss directly.

BIOENERGY TRACEABILITY AND LIFE CYCLE COSTS TRACKING WITH ONCE FUEL MANAGEMENT SYSTEM

Heikki Hämäläinen Protacon heikki.hamalainen@protacon.com

Abstract:

How to?
- Know Where Energy is Located, What Kind and How Much of Energy There is (in Feed Stocks, Terminals and Storages) and What is the Value of Energy Amount.
- Organize "Truck Flow".
- Manage Fuel Sampling and Laboratory Tasks.
- Get Information Needed for Accounts Ledger.
- Have an Easy Way to Trace Bioenergy all the Way.
- Easily Get Calculations of Bioenergy Life Cycle Costs from Forest to Boiler and Beyond .
- and Much More...

How to Take Care of These Things Easily, On time, Cost-Effective - Just Once - With Once

RESOURCE-EFFICIENT LAND USE – TOWARDS A GLOBAL SUSTAINABLE LAND USE STANDARD – ANALYSIS OF GLOBAL LAND USE CHANGE

Lutzenberger, A. K.
Leuphana University of Lueneburg
Scharnhorststraße 1, 21335 Lüneburg
alexa.lutzenberger@leuphana.de

ABSTRACT: Globalands is a project in cooperation with IINAS, Ecologic Institute, Karl-Heinz Knickel and Leuphana University of Lüneburg funded by the Federal Environmental Agency Germany. The aim of this project is to develop necessary drafts and strategic requirements for global accepted standards and policies to implement a "Global Sustainable Land Use Standard".
The debate of the sustainability of bioenergy in recent years focused more and more on the question of land use, because land use is the interface between climate change, fossil resources, biomass production and a few other points, but it is also part and driver of socioeconomic Interactions. The EU bound instruments and policies for the reduction of greenhouse gases, and for the raising of resource efficiency in national and international strategies, action plans and roadmaps. The thematic of land use is part of these policies, but just as a sub-item. In 2008 the German Advisory Council on Global Change (WBGU) postulates a global Land use management in the report "Future Bioenergy and Sustainable Land Use". This background was the reason for the "Globalands" Project.

Keywords: Land use, sustainability criteria, sustainability standards.

1 INTRODUCTION

In order to understand land cover changes and its underlying causes, first, the terms used "land use" and "land cover" should be clarified and delineated from one another. In the sixties, Burley (1961) [2] advocates making a distinction between land cover and land use. Up until then, the concept of land use had been attributed two meanings:
(1) the usage or the utilisation of the soil and
(2) the use or the intention of obtaining something from the soil. The latter also includes the (physical) environment, in which the action takes place, but caused confusion in the world of science, because the meaning of land use has been interpreted differently according to the field of research. In order to better differentiate both meanings, Burley suggested the term land cover. It comprises the covering of the soil surface, not only by vegetation, but also anthropogenic cultivation. In this context, the importance of the soil for human beings is not taken into account.
Up until today, the English-language expressions "land cover" and "land use" established themselves in international environmental research. Examples of relevant research projects are NASA Land-Cover and Land-Use Change (LCLUC) Program, Global Land Cover Facility (GLCF), UN Land Use, Land-Use Change and Forestry (LULUCF), (USGS) Land Cover Institute (LCI) or the Land-Use/Cover Change (LUCC) research project of the International Geosphere-Biosphere Programme (IGBP) and Human Dimensions of Global Environmental Change Programme (HDP). The Land-Use/Cover Change (LUCC) research project, laid the foundation stone for subsequent research projects (IAI, APN, START, NASA-LCLUC, Millennium Ecosystem Assessment) related to land uses- and land cover changes with his agenda and design, defines land cover as the biophysical status of the soil surface and of the subsoil, comprises biota, soil, topography, surface- and groundwater and built structures [9] [20]. By using the numerous biophysical parameters, land covers can be classified in various ways and different classification methods can be developed according to scientific purpose [20]. Typical broadly defined land cover classifications comprise for example forests, grassland, tillage, wet areas and non-biotic structures. Fitting sub-classifications are boreal and tropical forests, savannahs and steppes as well as villages and towns. Land cover changes can be defined in two ways: "conversion" and "modification". Land cover conversion means the complete replacement of a cover classification by another cover classification. Deforestation and burning of trees and of other vegetation, for example, in order to plant cereals afterwards, is a typical process of complete conversion of a forest area to tillage land [16, 17]. Other land cover conversions occurring can be forest to grazing land [5], tillage land to dwellings settlements [18] grass land to forest (renaturation) or dry lands to grazing lands [15].

1.1 Recording land cover changes

From a methodical point of view, land covers can be derived from remote-sensing image data [12] or are reflected in secondary statistics, such as census data of the FAOSTAT.
For data collection, not only for the remote-sensing image method, but also for census questionnaires, land covers are divided thematically in a specific

classification system classification systems and are normally structured according to hierarchy in several levels with various degrees of detail, they also contain criteria fit for the differentiation of land cover classifications between themselves [1].
Great endeavours were made by environmental sciences to document the changes in land cover and land use, in order draw models for future scenarios for sustainable land uses have, however, this lead to further challenges: in spite of the continuing improvement of satellite technology for remote sensing, there exists great data gaps concerning various land cover classifications and, because of that, knowledge gaps on the reasons and dynamics of these land cover changes.

1.2 Land cover classifications

Fundamentally, classification means abstraction. It is the theoretical representation of a really existing situation by using easily demarcated and well defined criteria [4]. Then before land cover can be classified, precise specifications must be made. In principle, it can be determined that classification systems mostly exist in hierarchical form. In these, classification criteria are selected, which only apply within one class and were formed in advance by more general criterion. By doing so, many levels are created, starting from subclasses, going from the more general to the more specific subclasses and develop into a classification tree [1,4]. Today there is no internationally recognised classification system. The reason for this is that every person working on classification does so in dependence of their research focus or matter in question and has a different notion of land cover classification or code.

1.3 Direct Causes

Direct causes include physical action on a land cover and can usually be attributed to a recurring series of activities, such as agriculture, forestry and infrastructure [11]. In the literature on deforestation, the direct causes are commonly classified into three broad groups [3, 10, 13]: agricultural expansion, logging and expansion of infrastructure.

1.3 Indirect Causes

By indirect causes basic are meant social driving forces, which lie underneath the more obvious direct causes. They consist of a complex of social, political, economic, technological and cultural variables and act contrary to the direct causes both at local level and at the national or global level. In global environmental research, a number of fundamental factors driving land use changes are being studies, in which five factors always repeatedly crop up as indirect cause: population, economic development, institutions, technology and culture [14].

2 ANALYSIS OF GLOBAL LAND USE

For the analysis of global land use, a total of 33 international studies as well as data collections were selected. These data collections were verified with regard three criteria:

- Plausibility of the classification and categorisation
- Comparability on a horizontal level with other sets of data
- Quality with regard a vertical comparison over periods to be defined.

For 1): A clear definition, which permits not only a clear, non-contradictory allocation to individual categories, as well as, furthermore, transparency of the allocation is very important for the other work packages. Moreover, this point also comprises the system delineation of the individual studies and the sets of data. For example, while there are various GIS datasets, but they often cross international borders and are thus not systematically available for this project.
For 2): When selecting the sets of data, these were compared as far as possible within the categorisations, in order to identify deviations. Sets of data from studies with great deviations from the mean have been rejected.
For 3): Vertical comparisons over certain time periods are a prerequisite for the identification of land use changes. Even though new studies and data collections have been published in recent years thanks to the improvement in methodology and data and information gathering, few fulfil the necessary comparability over long periods of time, so that many sets of data did not fulfil the requirements on this precise point.
After the verification, 3 data collections were selected for further treatment and analysis.
These sets of data have been transferred in a matrix and evaluated. Global land use is shown in the matrix, it is itemised for all countries. The changes in land use have been made visible not only in percentages, but also in the absolute of a set for all categories, on the other hand, for all countries of the world. This way, the “directions” taken by land use change have been presented in an overview picture.
In order to illustrate further influences of driving factors, the matrix has been extended. Here, 20 studies and sets of data with regard the above mentioned criteria were verified and selected in their turn. These sets of data, which have been added on, contain more detailed information, amongst others concerning population development, urbanisation, the growth of cities, infrastructure measures, economic development and resource extraction. By joining the data together in the final matrix, one can now identify the driving factors not only as countries, regions and continents, but also provide a global overview on land use, land use changes and changes of a certain number of already identified driving factors as well.

2.1 Results of the analysis according to land use categories:

First, the changes in land use from 2000 – 2010 were observed in individual categories and this was made each time in absolute numbers and in percentage values. In the category Forest Area for example, China has the largest absolute increase in forested area, whereas Ruanda shows the greatest increase with 26.45%. As expected, Brazil shows greatest loss of forested area in absolute, with a surface of 264,210 km^2. In relative terms, Nigeria lost, with 31.18%, an important part of its forest area.

Table I: Changes in the Category Forest Area

Forest area	**Changes in km^2**	**Changes in %**
China	298.610	16,87
USA	38.270	1,27
India	30.440	4,66
Ruanda	910	26,45
Uruguay	3.320	23,51
Tunesia	1.690	20,19
Brazil	-264.210	-4,84
Australia	-56.200	-3,63
Indonesia	-49.770	-5,01
Nigeria	-40.960	-31,18
Uganda	-8.810	-22,77
Pakistan	-4.290	-20,27

The next category presented here is the category Agricultural area.
Here, Argentina shows the largest increase in the absolute, while in percentage terms Oman, with 71.11%, has massively extended its agriculturally used area. Looking at the category irrigated Land shows that Oman, thanks to a decisive development of its irrigation systems, has been able to increase small agriculturally used area that is small in the absolute. The largest absolute losses appear in Australia, while the largest decrease in percentage terms of the agriculturally used area can be found in New Zealand.

Table II: Changes in the Category Agricultural Area

Agricultural area	**Changes in km^2**	**Changes in %**
Argentina	117.300	9,11
Indonesia	79.230	17,35
Niger	67.820	18,33
Oman	7.630	71,11
Armenia	4.305	32,54
Laos	5.100	27,78
Australia	-464.710	-10,20
Mongolia	-146.700	-11,24
Iran	-143.690	-22,85
New Zealand	-39.230	-25,45
Litauen	-7.290	-21,33

The category permanent meadows and pastures has a high relevance. The largest increases in this category are found in Argentina, in percentage terms, on the other hand, Estonia has the largest increase absolute. The largest losses in the absolute are found in Australia, in percentage terms however, they are in Denmark with -44.97%. It seems that there has been a massive ploughing of grassland in recent years there.

Table III: Changes in the Category permanent meadows and pastures

PMP Area	Changes in km^2	Changes in %
Argentina	86.300	8,64
Niger	57.820	25,14
USA	16.690	0,71
Estonia	1.960	149,62
Oman	7.000	70,00
Kambodscha	5.700	61,29
Australia	-463.820	-11,37
Iran	-170.760	-36,64
Mongolia	-144.560	-11,18
Denmark	-1.610	-44,97
Slovakia	-3.410	-39,42
Poland	-9.030	-22,12

The category other land is likewise important. There, all land use forms, which cannot be unambiguously classified, as well as infrastructure, built-up areas, and mountainous areas. Because of the important differences of the forms of use collected under this category, an unambiguous explanation concerning the changes in this category is very difficult. The largest increase in the absolute in this category is shown to have happened in Australia, in percentage terms New Zealand shows the most important changes. The largest absolute decrease has been observed in China; the largest decrease in percentage terms happened in Ruanda.

Table IV: Changes in the Category Other Land

Other Land	Changes in km^2	Changes in %
Australia	511.670	32,42
Brazil	211.326	54,76
Mongolia	154.070	116,99
New Zealand	39.116	147,50
Burundi	1.442	144,20
Slovakia	4.972	110,73
China	-192.138	-8,60
Argentina	-95.088	-8,41
Niger	-66.704	-7,55
Ruanda	-4.110	-90,73
Bhutan	-2.135	-69,39
Cuba	-5.974	-34,12

On the basis of this analysis, the following countries were selected for an individual country analysis in combination with identified driving factors: Argentina, Australia, Brazil, Kazakhstan, India, Indonesia, Nigeria, Poland, Russia, Sudan and the USA.

2.2 Comparison of land use changes in the selected countries

All the observed countries with the exception of India and Poland show a diminution of forested area. In the absolute, the largest forested area to have disappeared is in Brazil, with a total of 264,210 km^2 within 10 years. Though Nigeria shows, in percentage terms, the greatest cut back of forested area in the year 2000, in the absolute, it accounts 40,960 $km^{2.}$ Also in this magnitude, the losses of forested areas can be seen in Indonesia with 49,770 km^2 and in Australia with 56,200 km^2. The reforestations are noteworthy in India and the USA, whose magnitudes are of 30,440 km^2 respectively 38,270 km^2.

The largest losses in agriculturally used areas are found in Australia with a surface of 464,710 km^2, as well as in den USA with a total of 109,480 km^2. But also Poland lost 22,940 km^2, which roughly corresponds to the losses incurred in Nigeria, which are of 26,500 km^2. Conversely, not only Indonesia but also Argentina generated new agriculturally used areas of the magnitude of 79,230 km^2 and 117,300 km^2.

The field of permanent grassland is a sub-category of agriculturally used areas, however, changes here are especially climate relevant, because permanent grassland is among all agricultural uses, the type of use that binds the most carbon, therefore, if changes happen to it, it releases great amounts of CO_2.

The largest losses of permanent grassland in the absolute were found in Australia with a surface of

463,820 km^2. This corresponds to nearly the total losses in agriculturally used areas. A similar picture can be seen in Nigeria, where the proportion of the diminution of permanent grassland corresponds slightly more than 64% of the diminution of the agriculturally used area. In all other countries studied here, the losses are not particularly evident. Increases in the surface of permanent grasslands have been recorded for Argentina with 86,300 km^2, which corresponds to 73% of the increase of the agriculturally used area. Russia and the USA recorded slight increases at around 10,960 km^2 and 16,690 km^2.

As previously discussed, the category "other land" comprises a number of various subcategories. In general, the proportion of surface of this category is increasing. This also applies to Australia and Brazil. However, the countries, in which this category decreases very strongly, are interesting. These are Argentina, Indonesia and Kazakhstan. These effects will be described in more detail in the individual assessment of the countries.

Discernible population growth was found mainly in Nigeria and India. Surprisingly Australia's population also grew considerably. But the USA registered average growth, too. Not only Poland, but also Russia experienced decreases in the total population.

3 COUNTRY ANALYSIS: INDONESIA'S EXAMPLE

Indonesia occupies, with around 1.8 mkm^2, a small area, but with around 237 million inhabitants (2009), she has a large population. The population density averaged 131 inhabitants per km^2 [22]. The evident increase in urban population and the reduction of the country population from 2000 to 2009 highlight a serious rural exodus and the urbanisation trend, which is having negative consequences on the rural population involved. Indonesia's land cover was divided in 2009 in around 52% forested area, close to 30% agricultural land and around 18% residual areas. This means that Indonesia possesses a very large forested area. From 2000 to 2009, Indonesia's agriculturally used area grew by 0.079 mkm^2. Forest areas were the most affected by this increase: they decreased by 0.043 mkm^2. But the decrease of the remaining areas is not negligible. A closer look at the agriculturally used areas shows that increased tilled land and long-term crops are responsible for the loss of forested and residual areas. After considering all the crops listed in the FAOSTAT, it becomes obvious that the areas harvested where coconuts, maize, palm-oil fruit, natural rubber and raw rice grew the most within the same period of time. Thus, the increase of arable land can be explained by the increased space requirements of maize and paddy rice and the added space made for long-term crops with the rise in demand for palm-oil fruits and coconuts.

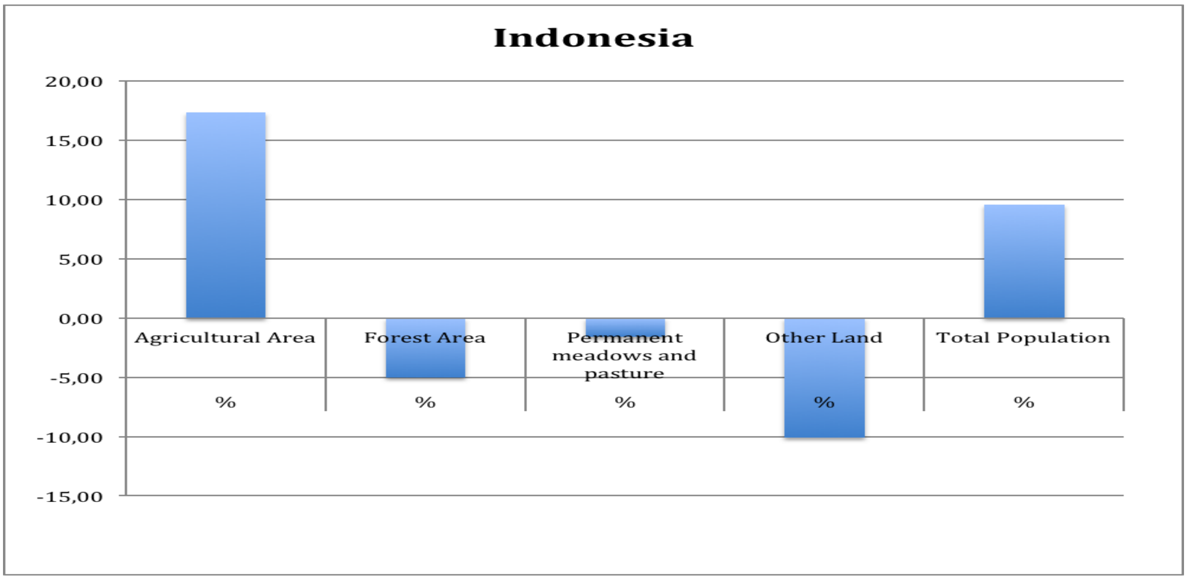


Figure 1: Indonesia Land Use Change

To sum up, it can be stated that: according to the findings of the study, the mosaic agriculturally used areas as well as fallow lands are mainly responsible for the decrease of the residual areas in Indonesia. Areas used for agroforestry are exclusively referred to as mosaic agriculturally used. The decrease in mosaic-type areas results from the increase in palm-oil plantations, perennial monocultures, as well as cash-crop plantations. Both last-mentioned descriptions can also include palm-oil fruit. Wet meadows as well as abandoned areas are also decreasing. In Indonesia the change in land cover is characterised mainly by the decrease in mosaic-type agriculturally used areas, in particular agroforestry areas. For a long time in Indonesia, agroforestry represented a traditional small peasant agricultural system, which was used in particular for the cultivation of cocoa and natural rubber.

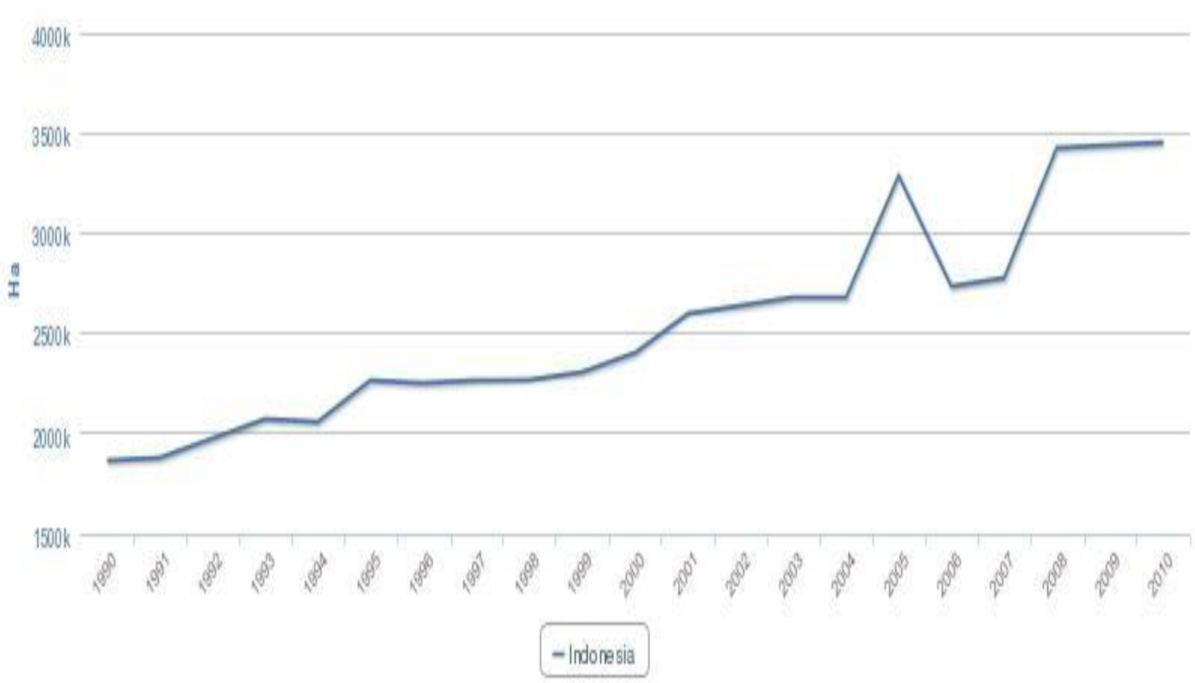


Figure 3: Indonesia Natural rubber area (Source: FAO STAT 2013)

Recent publications come to the conclusion, however, that the increasing disappearance of this type of agriculture in favour of an intensification and spreading out of agricultural and forested land, which is taking place in South-East Asia, is responsible for their sharp decline [6, 8]. The reason for this is the integration of the national economy in international markets, which are massively impacting the decisions of the local population to the detriment of agroforestry. Compared to natural rubber, palm-oil represents a very profitable source of income, because it can be used internationally to a great extent and in many situations of human life [7, 19].

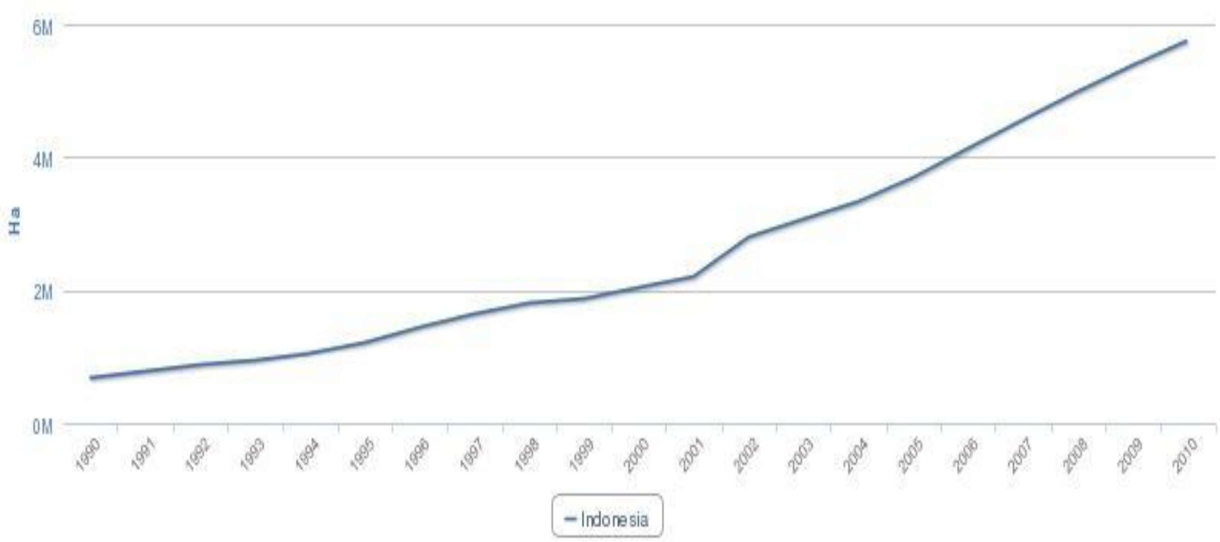


Figure 3: Indonesia Palm Oil area (Source: FAO STAT 2013)

However, a differentiating view is necessary, because palm-oil plantations alone cannot be made responsible for land use changes in Indonesia. Also the increased requirements for other cash-crops, such as coffee, increase the pressure on the local land cover. The extension of national economy to international export of palm-oil is causing the most important consequences for land cover Indonesia. The significant increase of rice paddies is directly related to high population growth.

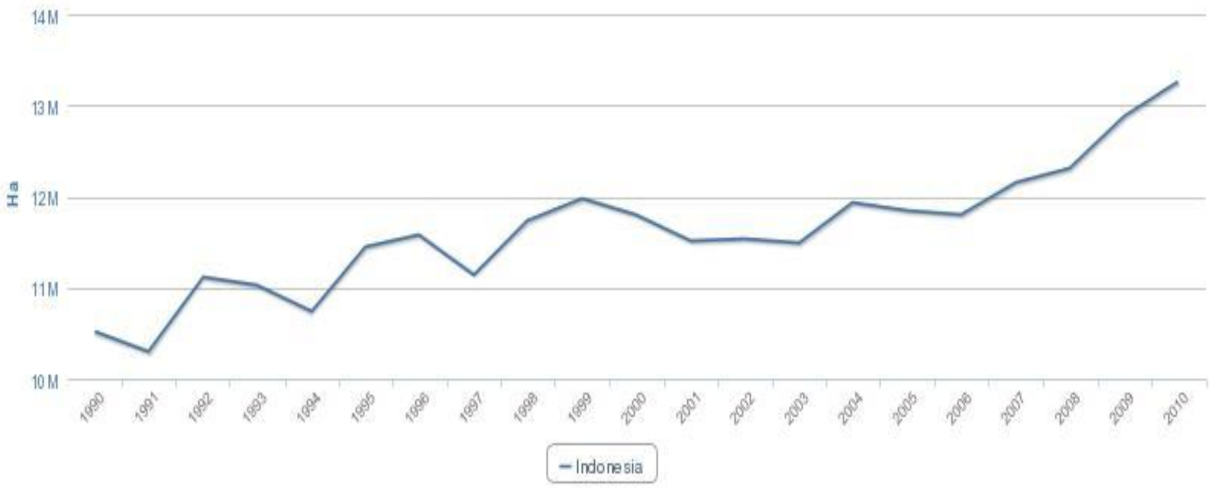


Figure 4: Indonesia Rice area (Source: FAO STAT 2013)

Rice represents the staple diet and is produced for the exclusive needs of her own population, the same applies to maize crops in areas unfit for rice production. The identified driving factors for land use changes in Indonesia are therefore mainly population growth as well as cash crops for international markets.

4 SUMMARY

As the Indonesian example for the causes of land use change shows, there aren't single drivers to identify as a main driver for observed land use change. The origin of land use change is in most analyzed cases a combination of different drivers. The proportion of the causing drives varies in connection to the status of the analyzed states in relation of the economical status, the climate zone and the social standards of the state. So summarized following conclusions can be done:

Land use change is reflecting identified drivers like:

- Cash crops in Indonesia (Palm Oil, natural Rubber),
- Population Growth in India, Indonesia
- Diet Change in India, China
- Growing GDP in Poland, China
- Mining in Australia
- Climate Change in Central Asia, China and Australia
- Bioenergy in Denmark, Germany, South America, USA, Indonesia
- Land Grabbing in Africa
- Security of supply Policies in Brazil, Argentina, EU, …..

and others..

BUT: it is not possible to identify single drivers as a main cause!

5 REFERENCES

[1] Anderson, J. R.; Hardy, E. E.; Roach, J. T.; Witmer, R. E. (1976): A land use and land cover classification system for use with remote sensor data. U.S. Gov. Print. Off. Washington, D.C.

[2] Burley, T. M. (1961): Land use or land utilzation? The Professional Geographer 13 (6): Pages 18– 20.

[3] Contreras-Hermosilla, A. (2000): The underlying causes of forest decline. Center for International Forestry Research. Jakarta.

[4] Di Gregorio, A. u. Jansen, L. J. M. (2000): Land cover classification system. Classification concepts and user manual - LCCS. FAO, Rome, Italy.

[5] Fearnside, P. M.; Imbrozio Barbosa, R. (1998): Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. Forest Ecology and Management 108 (1-2): Pages 147– 166.

[6] Feintrenie, L. und Levang, P. (2009): Sumatra's Rubber Agroforests: Advent, Rise and Fall of a Sustainable Cropping System. Small-scale Forestry 8 (3): Pages 323–335

[7] Feintrenie, L.; Schwarze, S. und Levang, P. (2010): Are Local People Conservationists? Analysis of Transition Dynamics from Agroforests to Monoculture Plantations in Indonesia. Ecology and Society 15 (4): Page 37.

[8] Garcia, C. A.; Bhagwat, S. A.; Ghazoul, J.; Nath, C. D.; Nanaya, K. M.; Kushalappa, C. G.; Raghuramulu, Y.; Nasi, R. uund Vaast, P. (2010): Biodiversity Conservation in Agricultural Landscapes: Challenges and Opportunities of Coffee Agroforests in the Western Ghats, India. Conservation Biology 24 (2): Pages 479–488.

[9]Gutman, G. (2004): Land change science. Observing, monitoring and understanding trajectories of change on the Earth's surface. Kluwer Academic Publishers. Dordrecht, London.

[10]Kaimowitz, D.; Angelsen, A. (1998): Economic models of tropical deforestation. A review. CIFOR. Bogor, Indonesia.

[11]Lambin, E. F.; Geist, H. (2006): Land-Use and Land-Cover Change. Local Processes and Global Impacts. Springer-Verlag, Berlin, Heidelberg.

[12] Lo, C. P. (1986): Applied remote sensing. Longman. Burnt Mill, Harlow, Essex, England, New York.

[13] Mainardi, S. (1998): An Economic Analysis of Factors affecting tropical and subtropical Deforestation. Agrekon 37 (1): Pages 23–65.

[14] Mather, A. (2006): Driving Forces. In: Geist, H. (Hrsg.): Our earth's changing land. An encyclopedia of land-use and land-cover change. Greenwood Press. Westport: Pages 179–185.

[15] Mitchard, E. T. A.; Saatchi, S. S.; Gerard, F. F.; Lewis, S. L. und Meir, P. (2009): Measuring Woody Encroachment along a Forest–Savanna Boundary in Central Africa. Earth Interactions 13 (8): Pages 1–29.

[16] Morton, D. C. (2006): Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences 103 (39): Pages 14637–14641.

[17]Nepstad, D.; Carvalho, G.; Cristina Barros, A.; Alencar, A.; Paulo Capobianco, J.; Bishop, J.; Moutinho, P.; Lefebvre, P.; Lopes Silva, U. und Prins, E. (2001): Road paving, fire regime feedbacks, and the future of Amazon forests. Forest Ecology and Management 154 (3): Pages 395–407.

[18]Seto, K. C.; Shepherd, J. M. (2009): Global urban land-use trends and climate impacts. Current Opinion in Environmental Sustainablility 1 (1): Pages 89–95.

[19]Steffan-Dewenter, I.; Kessler, M.; Barkmann, J.; Bos, M. M.; Buchori, D.; Erasmi, S.; Faust, H.; Gerold, G.; Glenk, K.; Gradstein, S. R.; Guhardja, E.; Harteveld, M.; Hertel, D.; Hohn, P.; Kappas, M.; Kohler, S.; Leuschner, C.; Maertens, M.; Marggraf, R.; Migge-Kleian, S.; Mogea, J.; Pitopang, R.; Schaefer, M.; Schwarze, S.; Sporn, S. G.; Steingrebe, A.; Tjitrosoedirdjo, S. S.; Tjitrosoemito, S.; Twele, A.; Weber, R.; Woltmann, L.; Zeller, M.; Tscharntke, T. (2007): From the Cover: Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. Proceedings of the National Academy of Sciences 104 (12): Pages 4973–4978.

[20]Turner, B. L.; Moss, R. H.; Skole, D. L. (1993): Relating land use and global land-cover change. A proposal for an IGBP-HDP Core Project : a report. International Geosphere- Biosphere Programme: A Study of Global Change and the Human Dimensions of Global Environmental Change Programme, Stockholm.

[21]Turner, B. L.; Skole, D.; Sanderson, S.; Fischer, G.; Fresco, L. und Leemans, R. (1995): Land-use and land-cover change. Science/research plan. International Geosphere- Biosphere Programme, Stockholm.

[22]UN OCHA (2005): Indonesia. Population Density. United Nations Department of Humanitarian Affairs. URL: http://reliefweb.int/map/indonesia/indonesia-population-density- 2005. From 3.9.2012.

6 ACKNOWLEDGEMENTS

Thanks to Mario Brillinger, who gives an important impact to this analysis with his Bachelorthesis "From other land to agriculture"- An analysis of Land use change from other land to agricultural area in Indonesia, Kazachsthan and Sudan, Sept. 2012

7 LOGO SPACE

Project management by

in cooperation with

on behalf of

funded by

BIOENERGY EDUCATION AND INDUSTRY & COMMERCE HAND IN HAND – CHALLENGES AND PRACTICAL SOLUTIONS

Varpu Savolainen, Hannariina Honkanen and Laura Vertainen
JAMK University of Applied Sciences, Institute of Natural Resources, Bioenergy Centre
P.O. Box 207, 40101 Jyväskylä, Finland
varpu.savolainen@jamk.fi
hannariina.honkanen@jamk.fi
laura.vertainen@jamk.fi

ABSTRACT: Bioenergy enterprises need well educated and trained employees in order to meet the growing demands of the sector. This is a challenge but also a great possibility for educational institutions as well as enterprises. In this article, we describe two different cases related to bioenergy education: 1) a special continuing education program designed for unemployed academic people, and 2) a new European training program for woodfuel production (WETNet). Companies working within bioenergy sector have pointed out several fields of know-how needed in the sector: e.g. service and maintenance, solid biofuel production, energy production in individual buildings as well as in small-scale district level (distributed heating systems), law and other regulation, logistics and planning of energy systems. Skills related to marketing and sales, project management, environmental permission procedures and land use planning are also mentioned in addition to more technical qualifications. Looking at any narrower sector within bioenergy, also the skill descriptions are more detailed. As an example, we describe a list of key skills required for woodfuel production (core competency standards in European level) that have been defined in the Wood Energy Training Network. The list covers all of the skills that are required to produce high quality woodchip fuel or firewood.

Keywords: bioenergy, renewable energy, continuing education, training, employment, skills

1 INTRODUCTION

One of the main constraints in the growing field of bioenergy is the availability of skillful and constant labor force. At the same time many European countries suffer from increasing unemployment, also amongst highly educated people. Hence, it seems that there are some structural challenges where know-how and skills do not fully meet the needs of the bioenergy industry or enterprises – or the potential of bio economy sector. Additionally, in bioenergy there are no ready-made degree programs that could directly produce professionals for all the needs in this wide field of expertise. But do we actually need such an educational program or, rather, is there more demand for continuing education or further training of people with previous expertise and experience in related fields?

In this paper, we describe two educational cases and approaches related to bioenergy. In the first case we describe our experiences from a special continuing education program designed for unemployed academic people. In our second case we describe the results and experiences gained from a Leonardo project called Wood Energy Training Network (WETNet).

2 NEW OPPORTUNITIES FOR UNEMPLOYED ACADEMIC PEOPLE?

2.1 Background

In the last few years JAMK University of Applied Sciences has gained good experiences in developing and running a continuing bioenergy education program for academic unemployed people having different backgrounds in areas such as applied life and natural sciences (biology and environmental sciences, chemistry, physics, agro-forestry…), in business and economics as well as in related fields of engineering and technology, e.g. material technology, civil engineering and wood technology. An intensive half-a-year-long bioenergy training program was developed in order to make potential employees and their expertise meet with the needs of bioenergy industry. The focus was, from the very beginning, practical, and we tried to meet the wide needs of the bioenergy companies as well as possible. Therefore, the curriculum was planned to be a more horizontally oriented rather than a very deeply focused on some specific issues.

So far the program has been completed three times in the region of Central Finland and once in southern Finland (coordinated by TTS). The idea in the program is to give students, i.e. university graduates, a wide and horizontal understanding of biomasses and their utilization focusing on energy use. Therefore, the curriculum covers different aspects related to bioenergy, starting from raw materials, biofuel production and logistics, and going through the whole chain to energy production and to end use of bioenergy, including environmental and quality issues, work safety and entrepreneurship, for example (see Figure 1). The earlier experiences and education of the selected students have been utilized throughout the training. In practice, students have very openly shared their experiences and knowledge, and proved to be cooperative and interactive also after the training program. We have found that it is very important to build up and enhance positive team spirit amongst the students and, at full stretch, respect the experiences of these adult people.

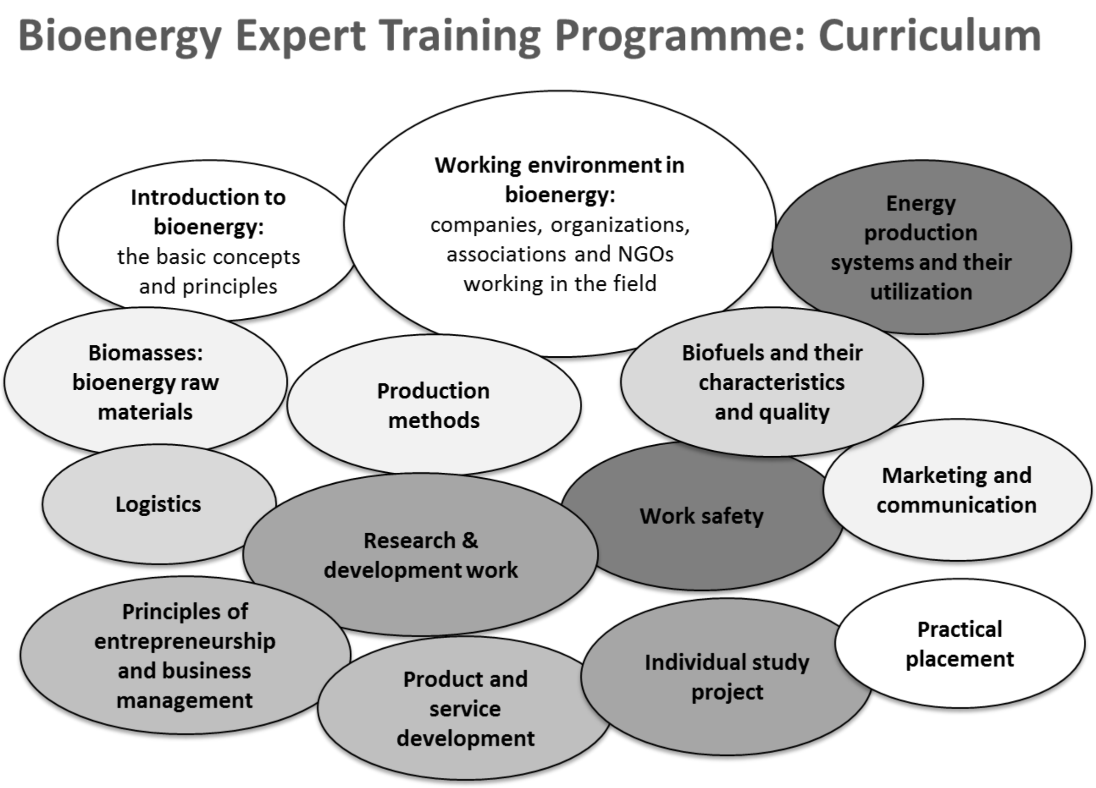


Figure 1. An overview of the curriculum in the bioenergy training program for highly educated people.

2.2 Close cooperation with companies

An essential part of our training program has been the practical placement period, the length of which has varied in our trainings from two to three months, i.e. from 1/3 to 1/2 of the whole program. Cooperation and communication between teaching staff, employer organizations and trainees him/herself are important. In the first course we tested also a mobile tutoring system utilizing mobile phones and internet. This proved to be a useful tool for communication, especially when there are long distances or other obstacles for a regular face-to-face communication.

Our students had their placements in different kinds of organizations, varying from big energy industries to SMEs specializing e.g. in consultancy services, in timber and energy wood haulage or in IT services. During the placement periods, students were given relatively challenging tasks related to, for example, product development, biomass or biofuel research, environmental assessment and sustainability, portfolio management, project preparation, participation in environmental permission procedures, logistics solutions, laboratory documentation, certification and quality management processes.

In addition to offering placements, several local and regional bioenergy companies participated in the program implementation by giving visiting lectures, by inviting students to study trips to mills or other production sites of the company, as well as by offering authentic subjects for students' individual study projects. In this way, the training program was kept closely linked to working life and their actual needs. We believe that this focus was appreciated by both potential employers as well as students themselves, some of whom had a very academic background with strong theoretical skills but with hardly any contacts nor experiences outside the university.

2.3 Feedback from students

The feedback from the students has been mostly positive. The students have mentioned e.g. the following pros: The new fields of know-how, new contacts and networks, professional teachers, interesting study visits, participatory teaching methods, "opening of new doors" and possibilities for employment and utilization of one's previous professional skills. Also some negative feedback has been given, e.g. the lack of deepness in some issues and overlapping of some subjects. All in all, the rate of employment during or right after the training program is the most important measure of impact and success of the program. In the first program, for instance, 12 students out of 15 were employed immediately. Unfortunately, the rate of direct employment in the latter courses was not as good, mainly due to the recession that hit quite heavily also companies in energy sector. A very positive phenomenon, however, was that quite many students seriously considered setting up their own business, e.g. in consulting or other services production. In addition, according to students' feedback, new inspirations about the possibilities in the renewable energy field as well as new information about the network of key experts and connections help students find opportunities and careers in the bioenergy related business.

2.4 Necessary fields of know-how in bioenergy – feedback from energy industry companies

We are currently in the phase of further developing the program and possibly also exporting it to other regions as well as working with new companies, local authorities and other players. It has been assumed that there may be needs to include other renewables and the energy efficiency issues to the next version of the educational program. New program could be implemented next in neighboring regions with some familiar conditions and existing partners in cooperation.

In summer 2013 ELY Centre of Pirkanmaa conducted a small-scale study in the region Pirkanmaa (incl. the city of Tampere) in cooperation with JAMK Bioenergy Centre experts. In this study representatives of the renewable energy industry in Pirkanmaa region were contacted and then inquired about their opinions and viewpoints related to educational needs in the sector. Altogether, 51 respondents from different size companies or other organizations having various specialization areas answered the digital questionnaire. Additionally, seven different types of organizations were chosen to be interviewed in more details.

The specialization areas of the companies involved in the study are presented in the following figure (Fig.2). The figure shows the wide variability in the need of the expertise in the sector of renewable energy. The public sector representatives (i.e. technical staff or authorities in municipalities) formed the biggest respondent group among the respondents from various organizations.

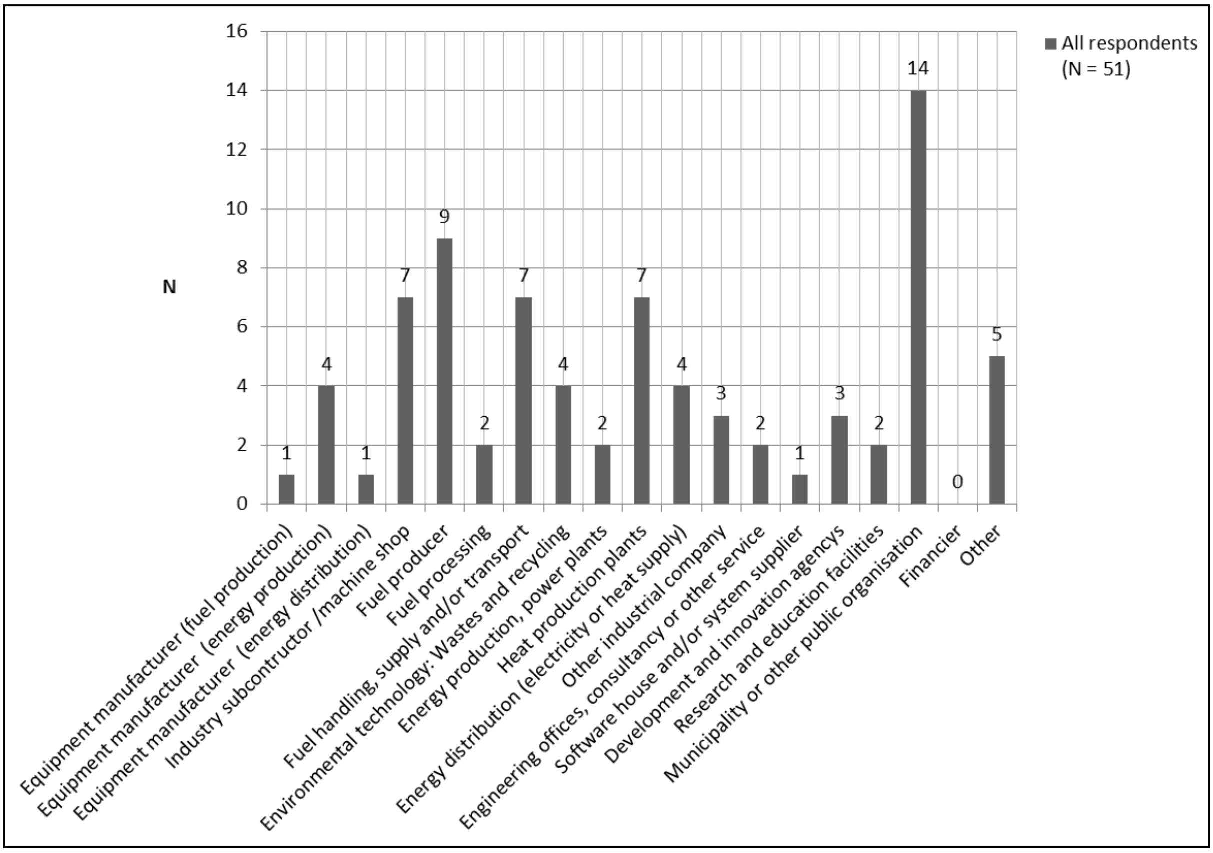


Figure 2. Background of respondent organizations. [1]

The range of the issues raised by the companies was even wider and more varying than the range of the companies. The respondents were asked what kind of know-how related to energy would be needed in their company in the near future. The feed-back of the respondents is stated in the following figure (Fig.3). It shows the percentage share of the chosen know-how needs in the questionnaire, given that it was possible for the respondents to choose one to five different options. This is a summary figure and does not directly show which issues were considered the most important. The study showed that for example expertise in law and other regulation as well as in services and maintenance are seen relatively as most important fields of expertise. The importance of regulation know-how is somewhat surprising. This may be due to the fact that energy policies and public regulations are considered somewhat unstable, unpredictable and therefore difficult to cope with. Legal expertise may be needed to be updated with different subsidies, taxation and environmental permission practices, for example.

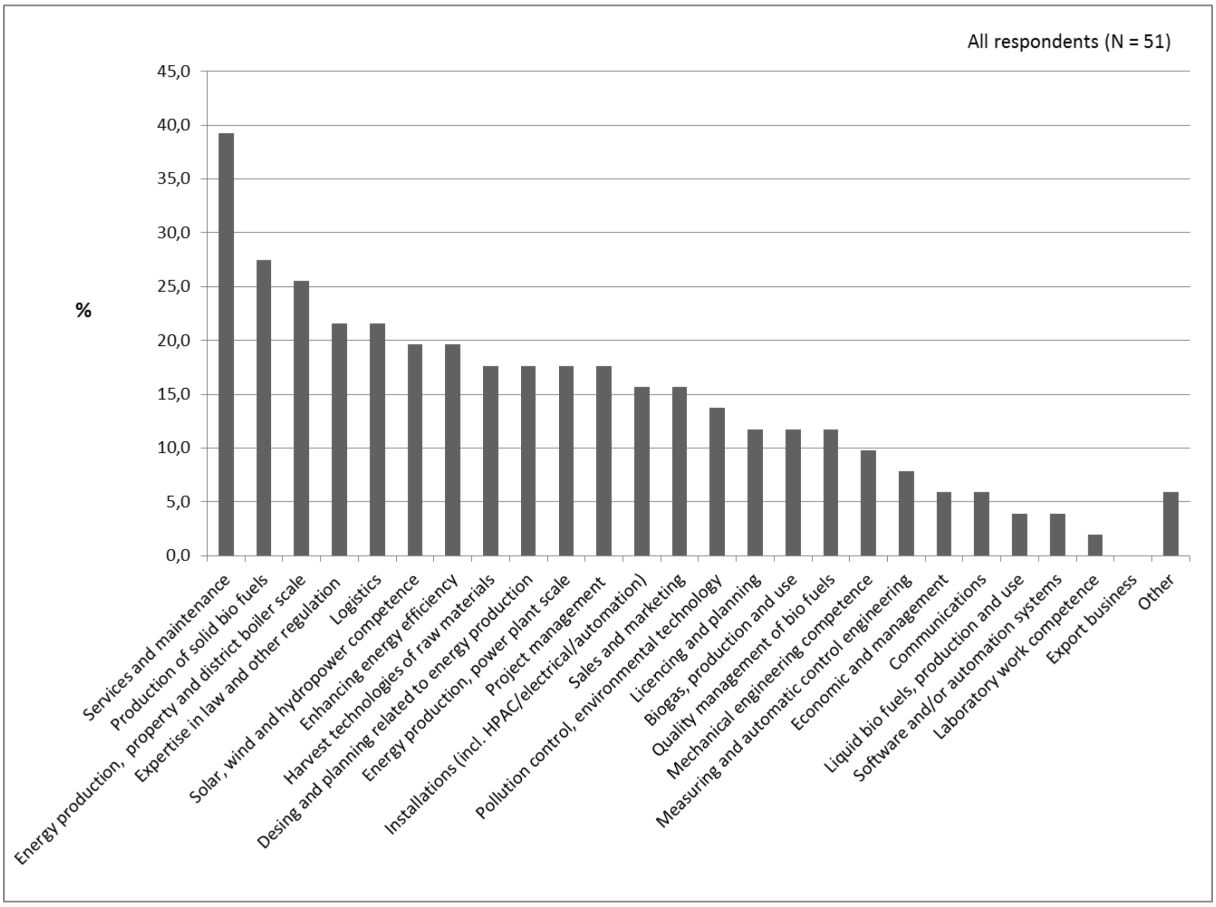


Figure 3. Example given by the conducted regional study about the fields of expertise needed in renewable energy sector. Opinions and assumptions by various companies. [1]

The results of the mentioned study are introduced more comprehensively in a separate seminar in Pirkanmaa region in near future.

3. INTERNATIONAL FUTURE – WETNet

Globalization and successful collaboration has been recognized to be one of the greatest possibilities and challenges within bioenergy business sector. To meet these demands and expectations JAMK has been involved in several international projects to create new networks and to enhance the possibilities for e.g. future educational export business. One of these projects is the Wood Energy Training Network –WETNet.

3.1 Wood Energy Training Network

The aim of the WETNet -project is to respond to identified needs within the forestry sectors of the partner countries for a transferable and integrated, pan-European approach to competencies and training in wood energy entrepreneurship, whilst creating a sustainable network of trainers from which to share and disseminate knowledge.

The WETNet project has seven partners drawn from six European countries: SAC Consulting (UK), Centre Forestier (France), JAMK University of Applied Sciences (Finland), Rural Development Initiatives (UK), Foundation Private Forest Centre (EMK),(Estonia), Turkish General Directorate of Forestry (OGM), (Turkey) and Fast Pichl (Austria).

3.2 European key core competencies of wood energy training

One of the targets of the project is to develop a set of core woodfuel sector competencies that will be applicable across Europe yet be able to reflect the needs of individual countries. The competencies reflect the nature of the existing sectors but also address future anticipated needs that will develop as the sector matures.

The purpose of the standard competencies is to raise the level of trainings and ensure that those participating in training gain the key skills they need to progress in the woodfuel sector, based on in depth understanding and gain a detailed working knowledge of best practice in the sector across Europe.

The key core competencies for producing woodenergy, i.e. by definition logwood and woodchips, were set by the WETNet project group consisting of specialists from each partner country. The skills already existing in the forestry and arboricultural industries were excluded unless they contained a unique element in relation to woodfuel.

The importance of each competence as well as the suggestions to develop further the constitution of the competence list was then inquired by questionnaires targeted to the selected experts of each partner country. The selected 47 competencies were divided under six headings:

- Woodfuel and Energy
- Woodfuel quality and properties
- Sustainability: Ecological, economic, social, cultural
- Woodfuel logistics
- Further processing of energy wood
- Woodfuel entrepreneurship

The number of respondents was altogether 99 and the ten most important competencies according to the survey were:

1. The importance of moisture content of woodfuels
2. Use of wood as a source of energy
3. Understanding of the economics of when timber can and should be used for woodfuel
4. Concepts of energy, forestry and woodfuel
5. Ability to judge the most efficient delivery /logistical system for a woodfuel product for a particular heating or combine heat and power system
6. Understanding the economics of fuel production and handling
7. Source of raw material for each product
8. Knowledge of the energy content of woodfuel products
9. Understand the economics of several logistic systems
10. Basics of energy technologies and processes

3.3 Training of the trainers

A woodfuel training programme has now been developed covering all of the key skills. At the first phase i.e. during the project the course is piloted and offered to the so called leading trainers and developed further to cover the diverse needs of European countries. These 30 leading trainers, 5 from each partner country will be certified and able to give the training courses to the trainers. The trainers are individuals working in forestry and woodfuel sector, or running a woodfuel business. The leading trainers and trainers from each country form the European woodenergy training network.

4. CONCLUDING REMARKS

In future the woodenergy training network, among other endeavors, gives possibilities to exchange expertise between partner countries, enhance the mobility of teachers, students and experts and develop novel solutions for the ever evolving educational needs of the developing sectors of renewable energy and bioeconomy.

In addition to international networks, we need closer cooperation also amongst national, regional and even local actors, including enterprises, educators but also authorities and education policy makers. The focus should be in increasing positive impacts of education and training programs. The task is challenging, but in a way also “a must”. Especially public resources for any education programs are getting more and more limited. Therefore we need to be more efficient and allocate diminishing resources wisely, taking into account future needs. Cooperation and interaction between different stakeholders within bioenergy sector is a key to success in this work.

REFERENCES:

[1] ELY Centre Pirkanmaa. 2013. Uusiutuvan energian alalla (ja erityisesti bioenergia-alalla) toimivien yritysten osaamis- ja työvoimatarpeen kartoitus Pirkanmaalla, selvitysraportti. Confidential. [only in Finnish]

[2] WETNet, The Woodenergy Training Network. 2003. Web-page of the project. http://www.eduforest.eu/progMindex.php?index=3

INSA – INDICATOR SYSTEM SUSTAINABLE AGRICULTURE

Alexa K. Lutzenberger
ALRENE Engineering office
Am Brink 3, 22929 Kasseburg, Germany
akl@alrene.eu

ABSTRACT: INSA is a project that was developed in a transdisciplinary master-course at the Leuphana University of Lueneburg under the supervising of the author Alexa Lutzenberger, who creates this project in relationship to another project “Sustainable agriculture”. It runs from April 2011 until March 2013 and was developed by two student groups from the mastercourse Sustainable Sciences. The project’s aim is the development of an indicator system called the Indicator System Sustainable Agriculture (INSA), featuring a set of 34 indicators. The system will be used to represent the level of sustainability of the agricultural region of North-East Lower Saxony, thereby showing where the possibilities for improvement for individual farms lie. It will also render the degree of sustainability of the agricultural sector representable and comparable not only at farm level but also aggregated at regional level. The farmers’ association “Bauernverband Nordostniedersachsen e.V. (BVNON)“ acts as a practical project partner of the project.

Keywords: Agriculture, Sustainability, Sustainability criteria

1 INTRODUCTION

Modern agriculture must increasingly come to terms with global challenges, such as climate change or the dramatic loss of bio-diversity, while sufficient foodstuffs have to be provided. Agriculture generates jobs. However, social aspects, such as working conditions are increasingly occupying centre stage. Furthermore, farms must be economically viable in the long term in order to be able to influence social and ecologic fields of action. Within the context of exacerbated challenges, sustainable agriculture is increasingly gaining in importance.

3 INDICATORS AND QUANTIFIERS

In order to be able to represent sustainability, it is necessary to quantify the subdomain, indicators, sub-indicators and items. The fundamental approach is that, when building sustainable agriculture, every one of the three fields of economics, ecology and society must be taken into account, that is to say each of them being counted as 1⁄3. The weighting method differentiates between three sub-levels. The first sub-level was developed with an expert forum. The weighting of the sub-indicators at the 2^{nd} level, as well as the items at the 3^{rd} was performed on the basis of extensive literature research, as well as from the results of the stakeholders’ dialogue. The assignment of numerical values to response options of items is referred to as “evaluation of the items”. In the whole questionnaire, the evaluation of the items comprises a five-step scale featuring the values zero to four. The numerical values zero to four of the response options are assigned to measuring indicators or to the sustainability performance. Therefore, each of the response options which is responsible for the worst sustainability performance is assigned a “zero” value. Response options, which provide the best sustainability performances are given four points. Dichotomous items possess the characteristics zero and four. An item has three response options and is given the values zero, two and four.

3.1 Economy

Because of the high number of 18 indicators in total representing the economy subdomain, every indicator is apportioned a rather low weighting.
The lowest weighting falls on the indicators farm size, farm insurance and independence of the operative parts. The highest weighting was given to the indicators non-agricultural potentials, returns on total assets, knowledge integration, return on equity, contribution margin and reinvestment. The indicators demand effect, promotion and non-agricultural potentials received four percent. The highest value of seven percentage points was achieved by changes in equity, return on assets and reinvestment. Then the weightings of the second and third level were carried out as well as the evaluation of questions items. As an example the indicator integration of knowledge is descripted with its sub-indicators and items and with a representation of the respective weighting and evaluation of the response categories. Below are details on the knowledge integration indicator by way of example to explain the weighting and evaluation table based on this indicator.

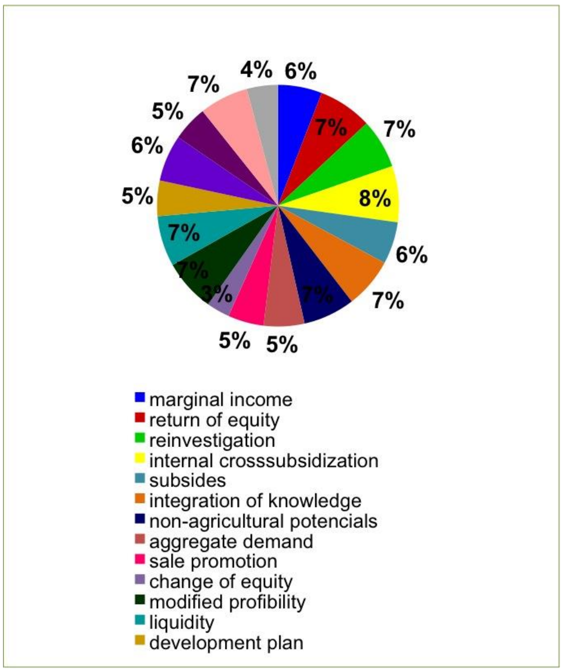


Figure 1: Economy Indicators

3.2 Ecology

In weighting carried out in the stakeholder dialogue, the indicator with the highest weight is the indicator soil (14%). The reason is that the compartment soil occupies a position, which is central to the sustainability of agricultural enterprises. The indicators energy and veterinary care (each obtaining 6%) achieved the lowest values. For the indicator energy the reason given was that the farmer has no influence on the consumption, which is already at its lowest possible level because of economic considerations, whereas veterinary care has been assessed as having only a low influence on the ecologic sustainability. The next step was the weighting on the second sub-level, that is to say the weighting of the sub-indicator between each other, which are included in the indicator as well as the weighting of the third sub-level, that is to say the weighting of the items between one another.

An aspect, which could possibly be considered unfair, is the fact that the farmers' initial situation is not included in the measurement of the sustainability performance. It is therefore understandable that a farmer, whose initial situation is tilling sandy soils, has a higher water requirement because the soil stores less humidity and therefore has higher water consumption than a farmer working on clay soil. It is the opinion of the project group to relativize water consumption in accordance to a difficult initial situation. It is a fact that too high a water consumption is not sustainable and is therefore the utilisation of agricultural areas on sandy soil, insofar as this is linked to higher water consumption.

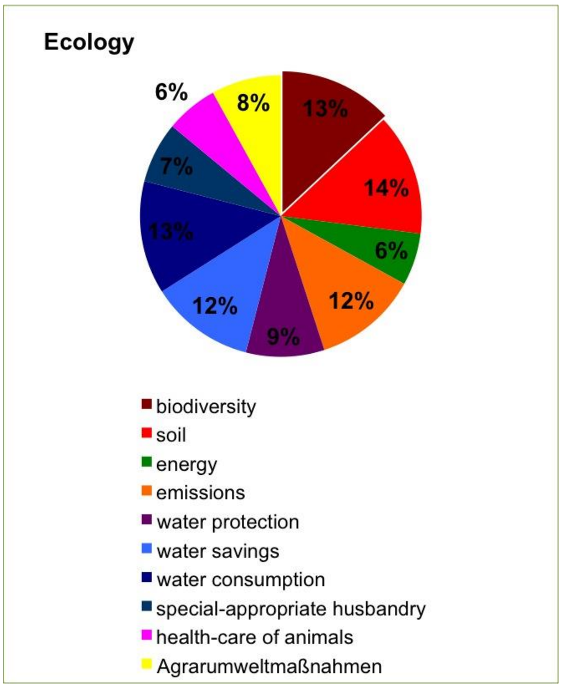


Figure 2: Ecology Indicators

3.3 Social aspects

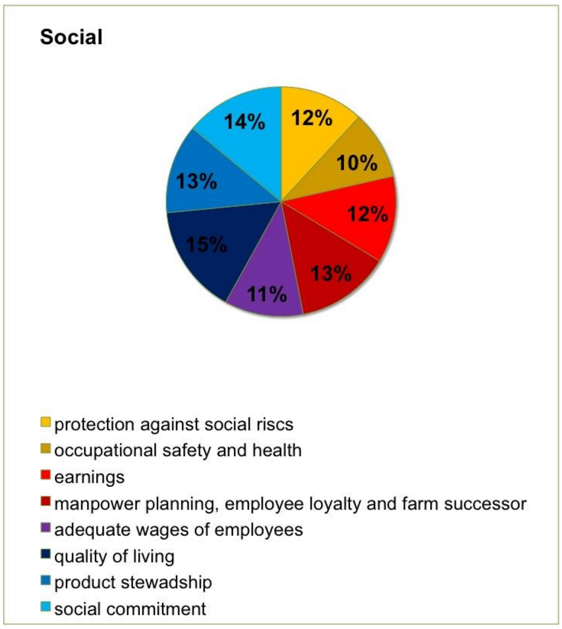


Figure 3: Social aspects Indicators

In the weighting one must take care not to assess farms without employees with lower grades than those with employees. It must be possible, therefore, to evaluate farms without employees without any of the several indicators. By doing so, the indicator remuneration of dependent employees drops out of the weighting. The indicator work-force planning, employee loyalty and succession of the farm, would, in such a case, be limited to the sub-indicator succession of the farm and only be included in this factor.

After the weighting had been completed at the first level the weighting of the sub-indicators in relation to one-another and the weighting of the items among themselves had to be carried out. In order to give the schema more clarity, a view of the weighting of the second and third level for the indicator work-force planning, employee loyalty, farm succession is provided. It is comprised of the five sub-indicators work-force planning, farm succession, training, employee loyalty and employee satisfaction. In this calculation, the sub-indicators have all been given the same weight (each 20%) in the indicator work-force planning, employee loyalty and farm succession. Each sub-indicator is queried in its turn with various items.

3.4 Questionnaire

The operationalization of the indicators and sub-indicators gave its shape to the questionnaire, which had to be validated and finalised. In doing so, the substance and meaning of the questions with regard the agricultural context was important. Moreover, a practical test had to be made to verify if the parameters asked could be gathered and were available. The rendition of the items was examined to determine if it was understandable. So the research team discussed the questionnaire together with the BVNON, made notes concerning the Questionnaire within the framework of the forum of experts and carried out a pre-test with a number of farms.

In order to test the *understandability* and the manageability of the Questionnaire and to receive feedback concerning the contents and scope, it was subjected to a two-tiered pre-test process. Because of limited time resources, quantitative pre-tests were dispensed with. Instead, a qualitative verification was carried out by means of cognitive surveys [1]. These surveys were conducted by applying the "thinking-aloud" method, which is a method used to generate information concerning knowledge and methods to solve human problems [2]. At the first stage, the Questionnaire was discussed with a representative of the BVNON, critical aspects were written down and lastly, they were made to fit the questionnaire. For the second stage of the pre-tests, three group representatives – local farmers – were asked to fill out the questionnaire by hand and to name all the thoughts that came to them while doing so. The commentaries were recorded point by point by the questioner on standardised report templates, sorted by field of activity and question number. The primary concern was a systematic representation. Therefore, the farmers taking the pre-tests were selected for having farms of differing sizes and agricultural types. The results of the pre-tests showed that the expression of the questions was, on the whole, understandable and that the farmers could answer them without inconvenience. However, it also became obvious that the questionnaire was too lengthy on the whole, making a reduction to its central issues necessary. Furthermore, certain questions required an adjustment as to their contents.

3.5 Evaluation of items

A further stage in the finalisation of the questionnaire was the evaluation of the items. First, the evaluation scale applicable to all the items had to be developed, which attributed a number of points to each of the items, thereby making the sustainability performance of the farms measurable and comparable. This was followed by the evaluation of the items proper, by assigning a number of points on the evaluation scale to each of the items on a scientifically confirmed basis

3.6 Selection of the evaluation scale

For the evaluation of the items, a five-tier scale with score characteristics ranging from zero to four has been selected. This enabled an illustration of the sustainability performance by assigning the points obtained to the individual response options. This means zero points will be assigned to the response option corresponding to the lowest sustainability performance and four points to the most sustainable response option.

The evaluation of the items using the specified evaluation scale means that a measurement is being carried out, because it constitutes an "assignment of numbers (G) to objects according to specified rules" [3]. To achieve this, the items which measure the sustainability performance of the farm were measured.

4 METHODOLOGICAL APPROACH

What is important in this instance is that the relationship of the measured objects to each other is reflected in the assigned measurement values and that, through this, the measurements show a structurally correct picture. Furthermore, it is necessary that the measured objects can be classified according to their characteristics [3]. In the case of the evaluation of the items of the questionnaire, individual response categories of the items be classified according to sustainability criteria, whereby the most sustainable response category is assigned the highest number of points. In many items, there is a build-up of equivalence classes where the response categories can be immediately evaluated with regard the sustainability of the farm and receive the same number of points. Such an attribution of measurement values is described as homomorphous. However, if no response categories are grouped in equivalence classes and exactly one numerical value can be attributed to every response category, this is termed isomorphous distribution [3]. In the evaluation of the items, both homomorphous and isomorphous distributions, depending on the item and corresponding response categories, were used.

Moreover, the scale used for the evaluation is an ordinal scale. This enables the examination of the equality of the response categories (by creating equivalence classes) and a ranking of the response categories with respect sustainability performance of the farm. The ordinal scale used, does not permit any conclusion as to the intervals between two successive response categories, that is, it is not possible to classify a response category, which received two points in the evaluation as twice as sustainable as a response category, which received only one point in the evaluation [3]. Since conclusions cannot, or not easily, be made on the intervals of the individual response categories in a major part of the items, an ordinal scale was selected for the evaluation of the items.

Furthermore for the evaluation of the items, a five-step scale was selected. For the evaluation, a scale with an uneven number of steps was necessary in order to obtain a scale with a middle point to be able to measure in accordance with legal requirements. The advantage of a five-step scale lies in the fact that it offers more adjustment and differentiation possibilities than a three-step scale. However, the difficulty of delimitating individual points on the scale between each other is kept at a low level [4].

5 RESULTS

In what follows the procedure and evaluation of the pre-test data is presented, the advantages and draw-backs are reviewed as well as, alternative evaluation methods, if any, are outlined. It should be noted that no refined evaluation concept was developed. This paragraph merely aims at showing reflections and approaches, which will need further attention following the handing-over of the project, to be checked for applicability and undergo concrete overhaul. The evaluation of the data from the pre-test was made after the evaluation of the response categories and the weighting of the indicators on all three weighting levels (see chapter 3.4). The data from the filled-out questionnaires were transferred into a weighting and evaluation grid by using Excel spread sheets.

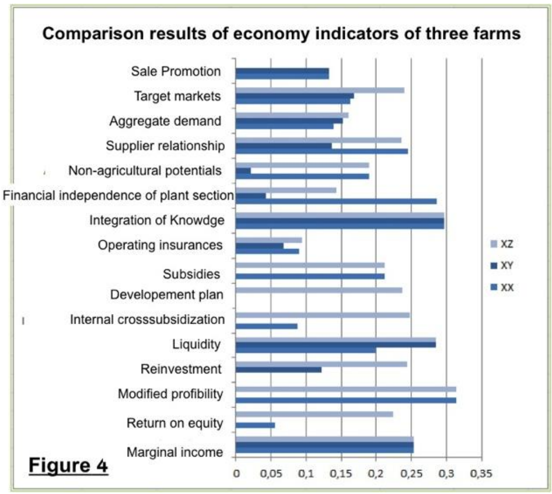


Figure 4: Comparison of economy indicators

Figure 4 shows a comparison of all the three farms that participated in pre-tests for the indicators in the field of economics. Each column colour represents one farm and enables a direct comparison. Here, too, the weighting indicators are linked to each of the points achieved. The latter, combined with the greater number of indicators in the field of economics justifies the lower total score, which was achieved by the farms in comparison to the field of ecology through the farms.

In conclusion, the diagram below represents an aggregate total for the three pre-test farms across all indicators within one field, here, for the economical field. These simple and oft-used column diagrams provide outsiders with rapid access to the data collected.

Next to column diagrams, there exist still further easily understood illustration forms. One of them is referred to as spider diagram, where farms could also be compared by using the aggregated indicators. Figure 5 shows the sustainability performance of an imaginary farm A (grey line) compared to the average performance of all farms surveyed (red line).

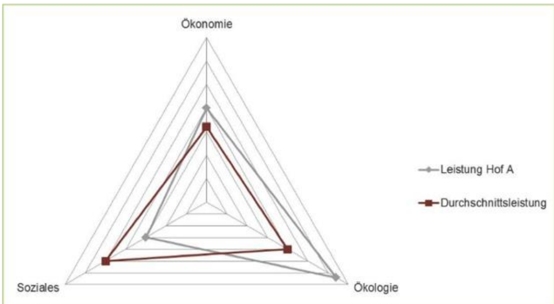


Figure 5: Results Pre-Test

Figure 5 shows, like the previous figure, a comparison instrument for the farms investigated. The visualisation of the average performances provides furthermore an overview of the sustainability performance of the farms in the Region of North-East Lower Saxony for the BVNON. Thus, there is a usefulness at intermediary level.

The usefulness at farm level, however, lies in the identification of improvement potentials in the farms. Furthermore, the data collected will also serve as means of communication by individual farmers and must therefore be prepared as descriptively and close to practice as possible. Accordingly, an understandable and descriptive visualisation of the sustainability performance of the farms surveyed, including all strong and weak aspects, is of great importance. It is planned that the data treated will serve the farms as a basis for the assessment of the farm performance and, through this, promotes farmers' own initiative for example with regard the use of consultancy services. In order to achieve such transparency in the representation of sustainability performance of agricultural enterprises, it must be taken into account that the recipient of the data (BVNON and the farmers) are primarily non-scientists. An understandable access to the data and its self-explanatory representation can, after all, serve to remove barriers between scientists and non-academics, which is in keeping with the trans-disciplinary project.

Agriculture provides a good basis for change towards sustainability, as intergenerational justice, sustainable economies and a good use of own resources of the agricultural operation are inherent qualities. But it faces many obstacles and must come to terms with problems that the individual farmer can hardly tackle alone. This is due in large part to the predominance of economic constraints and the dependence of unfavourable and controversial political conditions. But also the attitudes and value estimates of consumers to food and thus to the work of farmers are at best be described as ambivalent. The indicator system can be used as a measuring instrument for making both deficits and successes visible and, in this way, identify possible fields of action as well as improvement potentials and demonstrate positive qualities, thereby making them communicable. It can, therefore, result in an impulse for a political change of direction and inspire social discourse. Both are absolutely necessary if sustainable agriculture is to have a chance in the future.

6 REFERENCES

[1] Mittag, O.; Böhmer,S.; Deek, R.; Ekkernkamp, M.; Hüppe, A.; Telbis-Knkainen, H.; Raspe, A.; Raspe, H. (2003): Fragen über Fragen:cognitive survey in der Fragebogenentwicklung. In: Sozial- und Präventivmedizin 48, Nr.1 Pages 55-64.

[2] SOmeren, M. W. van; Barnard, Y.; Sandberg, J. A. C. (1994): The Think Aloud Method. A practical guide to modelling cognitive processes. London. Academic Press

[3] Schnell, R.; Hill, P. B.; Esser, E. (1999): Methoden der empirischen Sozialforschung. 6. völlig überarbeitete und erweiterte Auflage München/Wien: Oldenbourg.

[4] Porst, R. (2011): Fragebogen: Ein Arbeitsbuch; VS Verlag für Sozialwissenschaften/Springer Fachmedien Wiesbaden GmbH

MASTER OF WOOD ENERGY (EWOOD) – A NEW MASTER PROGRAM FOR WOOD ENERGY SECTOR

Tapani Tasanen
Seinäjoki University of Applied Sciences
Kalevankatu 35, FIN 90100 Seinäjoki
Tapani.Tasanen@seamk.fi
Tel. +358408304132

ABSTRACT: **Master of Wood Energy** project produces a new international study program for wood energy sector. Seinäjoki University of Applied Sciences and partner institutions from Great Britain (Scotland), Hungary, Italy and Spain are planning a new Master's course, which is started first time in October 2014. Additional information is available on Inverness College UHI's web page http://www.inverness.uhi.ac.uk/training-and-enterprise/whats-new.

The aim of this 3-year project, funded by EU as a part of **Erasmus Multilateral Programme**, is to plan a master program for educating experts in wood energy production, trade and transportation as well as modern R&D methods, within the EU and globally. The EU has set very challenging aims for the partial replacement of fossil fuels with renewable energy by 2020. In many EU countries forests are a remarkable source of renewable energy and wood energy is an important export product. Correspondingly there are several EU countries where renewable energy resources are limited. For these reasons the international trade of wood energy is inevitable and increasing. The technologies for wood energy production, transportation and use are developing rapidly both inside and outside the EU. Increasing numbers of professionals who know the latest technology and international trade rules as well as environmental aspects are needed. Starting the international education of wood energy professionals is the best way to meet future challenges. Our consortium consists of six of the most outstanding higher educational institutes and bio-energy research organizations from different parts of Europe.

The planned master program will be based on former B.Sc. or equivalent studies, primarily of forestry or other bio-sciences. The consortium will plan a 2-year joint/double degree program consisting of the following studies:

- silvicultural methods and forest management systems for energy wood production
- harvesting, measurement, transportation, drying and refining of energy wood
- production of heating energy and electricity in wood energy based heating and power plants
- wood energy trade, customs regulations, legislation inside and outside the EU
- wood energy economy: profitability, public support etc.
- environmental issues concerning the production, transportation and use of wood energy
- a thesis related to a wood energy topic
- training periods in the student's home country and abroad

Through this project the EU's education, energy and environmental policies meet at the campuses.

The members of the consortium are:

-Seinäjoki University of Applied Sciences (coordinator, Seinäjoki, Finland)
-National Research Council, Timber and Trees Institute CNR-IVALSA (Florence, Italy)
-Inverness College UHI, University of the Highlands and Islands (Inverness, UK)
-University of West Hungary (Sopron)
-Forest Sciences Center of Catalonia CTFC (Solsona, Spain)
-University of Lleida (Lleida, Spain)

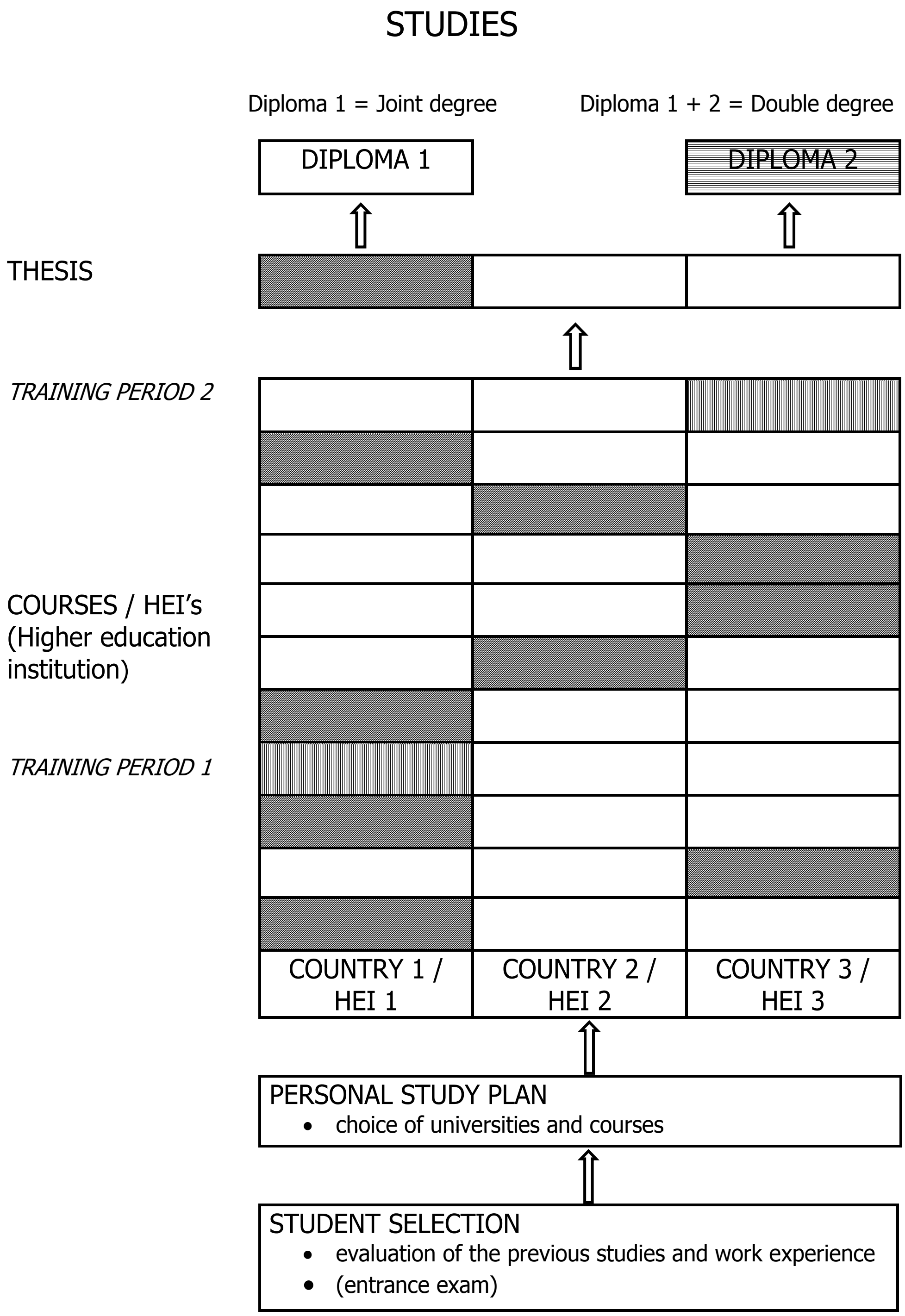


Figure 1. Structure of the master program when the student makes the courses, training periods and thesis work in three countries. The first study group will start in October 2014.

STRATEGIC PROCESS SUPPORTING BIOMASS ORIENTATED RESEARCH-DRIVEN CLUSTER DEVELOPMENT

Kirsi Knuuttila[1], Heikki Malinen[1], Goizeder Barberena[2], David Sánchez[2], Ines Echeverría[2], Chrysovalantis Ketikidis[3], Panagiotis Grammelis[3], Ingrid Krissakova[4], Milan Oravec[4], Marek Hryniewicz[5], Anna Gryzbek[5]
[1]JAMK University of Applied Sciences, PO BOX 207, FIN-40101 Jyväskylä, Finland, Kirsi.knuuttila@jamk.fi
[2]National Renewable Energy Centre-CENER. Ciudad de la Innovación 7, 31621 Sarriguren. Navarra. España, gbarberena@cener.com
[3]Centre for Research & Technology Hellas/Institute for Solid Fuels Technology & Applications. 4th km. Ptolemais-Mpodosakeio Hospital P.O. Box 95 GR 502 00 Ptolemais, Greece, ketikidis@lignite.gr
[4]National Forest Centre-Forest Research Institute, T.G. Masaryka 22, 960 92 Zvolen. Slovak Republic, krissakova@nlcsk.org
[5]Institute of Technology and Life Sciences Warsaw Branch. Rakowiecka Str. 32 02 532 Warsaw, Poland, marek.hryniewicz@wp.pl

ABSTRACT: Five European regions – Central Finland, Navarre in Spain, Western Macedonia in Greece, Slovakia, and Wielkopolska in Poland – have carried out a strategic process to strengthen their regional research-driven clusters. This has improved research as well as research-related innovation environment. In 2010 regions provided the regional Strategic Research Agendas (SRAs) for sustainable use of biomass. The SRAs set the development targets by 2020 for the regional research driven clusters. The SRAs were facilitated by the regional Joint Action Plans (JAPs). JAPs defined the measures and required human and financial resources as well as networks to achieve the strategic targets. Five regions produced also the mutual joint action plan that introduced co-operation and integration of the cluster regions in the field of biomass research related activities and innovation commercialization. By now the strategic process has been facilitated by large number activities. The networks have developed during the large number of personnel exchanges. The expertise and competence of the regional clusters have been improved by participating in regional, national and European initiatives. Furthermore the research related innovation management has been analyzed and developed. In general the process has improved the research activities in the target regions. It has also improved the competitiveness of the regional biomass based businesses.

Keywords: sustainable use of biomass, research agenda, joint action plan, research-driven cluster

1 REASONS TO DEVELOP BIOMASS ORIENTATED RESEARCH-DRIVEN CLUSTERS

Five European regions – Central Finland, Navarre in Spain, Western Macedonia in Greece, Slovakia, and Wielkopolska in Poland – have carried out a strategic process to strengthen their regional research-driven clusters. The work was carried out in EU 7th Framework Programme as Regions of Knowledge project called "Developing Research and Innovation Environment in five European regions in the Field of Biomass Resources - BIOCLUS" (www.bioclus.eu). The project objective was to boost the regional competitiveness and growth. It has promoted collaboration and integration of cluster regions and strengthened the innovation environment by improving research potential and innovation management. Besides, the project has supported sustainable development by improving the use of biomass resources. The development was achieved by:

- Promoting scientific, strategic and business competence at cluster and consortium level
- Developing collaboration capabilities in the clusters and consortium level
- Improving innovation to business environment by mutual learning and by mentoring

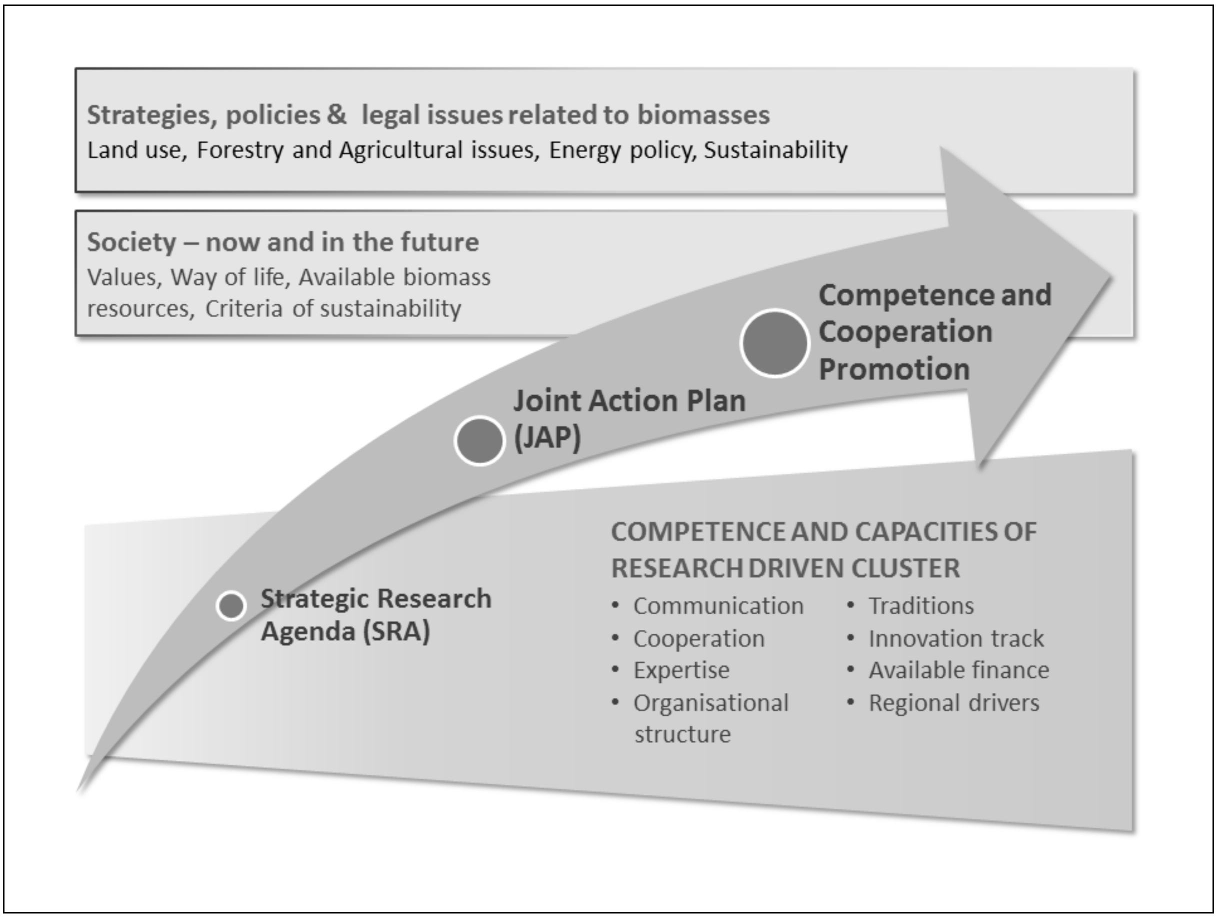
The **BIOCLUS research driven clusters** locate European perspective in rural regions and all possess great biomass resources such as forests, agriculture, industrial and agricultural by-products as well as municipal waste. In general, biomasses are challenging raw material. The utilization chains require special technical and practical competence as well as applications. The global trend is that renewable resources are replacing non-renewable resources. However, the use of resources should be efficient and sustainable. Therefore, the regional research driven clusters aim to improve the RTD activities and innovation systems. Furthermore, the biomass resources offer great possibility to BIOCLUS regions in economic and social terms.

The biomass related businesses have great influence in the regional economies in the cluster regions of BIOCLUS project. Every region has unique operational environment but the challenges are common. Before the project the regions had recognized following development needs:

- To promote the co-operation between the regional actors
- To create the regional level strategy for sustainable biomass use
- To improve the research environment & activities in regional and international level
- To develop the innovation related activities by benchmarking and mentoring partner regions

All clusters have strong research, development and training resources and tradition. However, in the future all human and natural resources should be used more efficiently and in as sustainable way as possible. This offered possibilities and challenges to BIOCLUS consortium.

The biomasses are regional resources. Typically growing, harvesting and processing are regional activities and provide employment. The biomass related industries and SMEs have favourable development drive due to improved innovation platform. The links between the regional authorities, RTD entities and regional businesses are strengthened and the creation of European research network facilitated. The collaboration is utilized in development of the regional level strategic research and development agendas (SRA) that support sustainable and multi-functional use of biomasses. That promotes the ecological, economic and social development in biomass resource utilization.



BIOCLUS strategic development track.

2 TRACK TO THE STRATEGIC PROCESS – BIOCLUS MEASURES IN PRACTICE

2.1 Regional Strategic Research Agenda (SRA) process

The starting point for **Regional Strategic Research Agenda (SRA)** process was the comprehensive understanding of regional biomass resources and operational environment. Therefore the following analyses were produced at regional level:

- Analysis of existing innovation environment including financial opportunities
- Analysis of the business potential in the field of sustainable use of biomass resources
- Analysis of biomass production, processing, logistics and use
- Analysis of regional biomass potential
- Analysis of existing research and development resources and activities
- Mapping the operational context, e.g. regional, national and European legislation and initiatives
- SWOT analysis from the perspectives of RTD and the regional economy

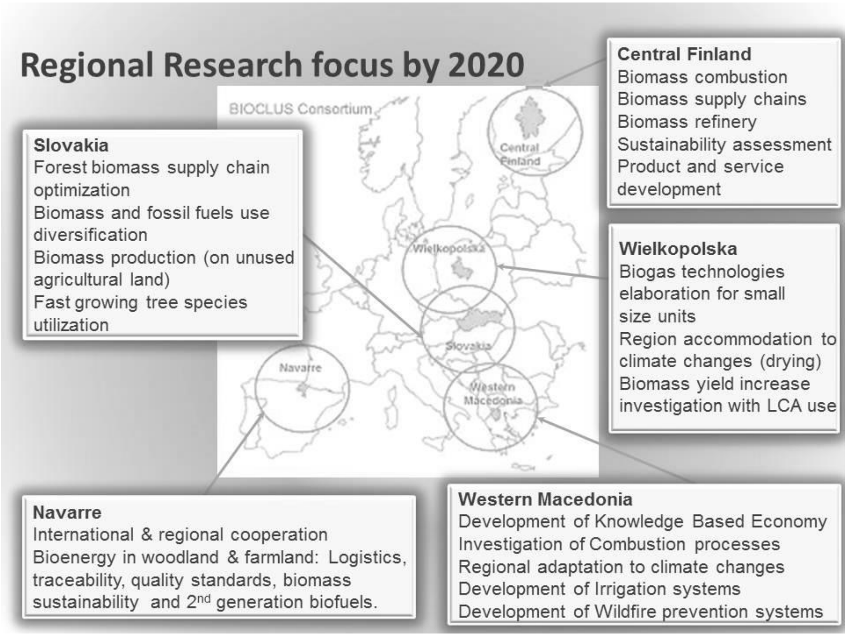
The SRAs support expertise development and cooperation in the regional research-driven cluster. They identify the future regional research focuses and support the authorities in directing the use of human and financial resources. The regional focuses are introduced in Figure 2.

These strategic research areas are defined in terms of concrete steps, priorities and development action in the Regional Joint (Research) Action Plans.

2.2 Joint (Research) Action Plan 2020 implementation

The Regional Joint Action Plan 2020 defines how to support regional development, co-operation and integration of the research-driven cluster in the field of sustainable use of biomass resources by 2020. Regional research and development organizations in cooperation with the regional authorities and companies have selected the regional development priorities. The starting point has been to identify the means how to create higher export earnings for companies as well as support regional business development and thereby increase the competitiveness and well-being of the whole region. Companies in Central Finland consider that the selected development priorities will generate business value-added in global markets.

The SRA development and the production and implementation of JAPs offer new opportunities for the regions involved. The Joint Research Action Plans strengthen their regional research-driven clusters by increasing the expertise, helping the clusters to apply EU research funding, and by offering a channel to actively participate in regional, national, and European networks.



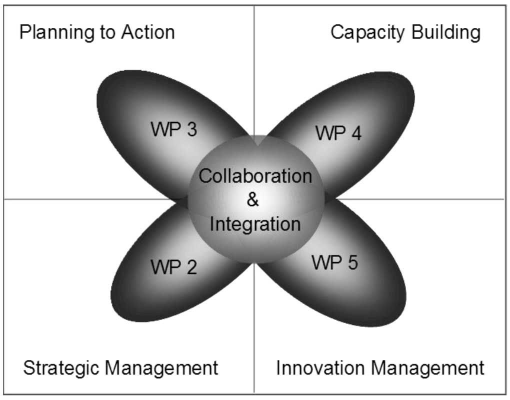
Regional Strategic Research agendas (SRAs) support regional research related capacity building and improve cooperation at regional and European level. The regional biomass related research focus of BIOCLUS regions by 2020.

BIOCLUS project offered an extraordinaire opportunity to facilitate the regional research driven cluster development. During the project the partners implemented capacity building, competence promotion and networking. The project organised five international study tours (*Agrobiomass logistics, Energy crops and their cofiring potential, Forest biomass production and energy production, Biomass study tour, Agrobiomass* *cofiring targeting high efficiency for CHP*) and JAP facilitation workshops (*Agrobiomass logistics, Cofiring of herbaceous biomass , Forest Biomass use in energy production, Sustainable Use of Biomass, Agrobiomass cofiring targeting high efficiency for CHP*) for biomass professionals with background in research, development and training, large number of events for peer entities, for authorities and for public, many expert exchanges at cluster and consortium level. Besides, the clusters built their capacities by participating in the seminars, conferences, study-tours, workshops and other events at regional, national and international level. These activities supported strongly the strategic work as well as initiated the joint actions of the cluster regions and the consortium of five European regions involved in the process. The project promoted activities targeting further research and development, training and innovation cooperation.

2.3. Research-related innovation environment development

The cluster regions analysed their existing **innovation systems and innovation environment** as well as recognised the improvement needs. Some regions focused on the general innovation system development and some regions on research related innovation system development. The regions had great opportunity to improve their system by learning by benchmarking visits to two successful regions (Michigan Keweenaw area & Styria, Austria) and by promoting and learning best practices and by mentoring process.

Strategic collaboration and integration in terms of research and innovation management.



3 IMPACTS OF BIOCLUS

The BIOCLUS clusters locate in the rural regions and all possess great biomass resources such as forests, agriculture, industrial and agricultural by-products and residues as well as municipal waste. The biomasses are challenging raw material. The utilization chains require special technical and practical competence as well as applications.

The global trend is that renewable resources replace non-renewable resources. Besides, the use of resources should be efficient and sustainable. Therefore, the clusters aim to improve the RTD activities and innovation systems. Furthermore, the biomass resources offer great possibility to BIOCLUS regions in economic and social terms.

In general BIOCLUS was very successful project in many terms. It was inspirational and offered great opportunities to all participants. This was seen strongly from the commitment of the project entities. There were no changes in the consortium of 20 organizations during three year project. Also the key persons were same over the project life cycle. The large consortium was the strength of the project due to extraordinaire expertise concentration. Whereas it gave some challenges to communication and information dissemination to relevant entities.

3.1 European additional value of strategic process

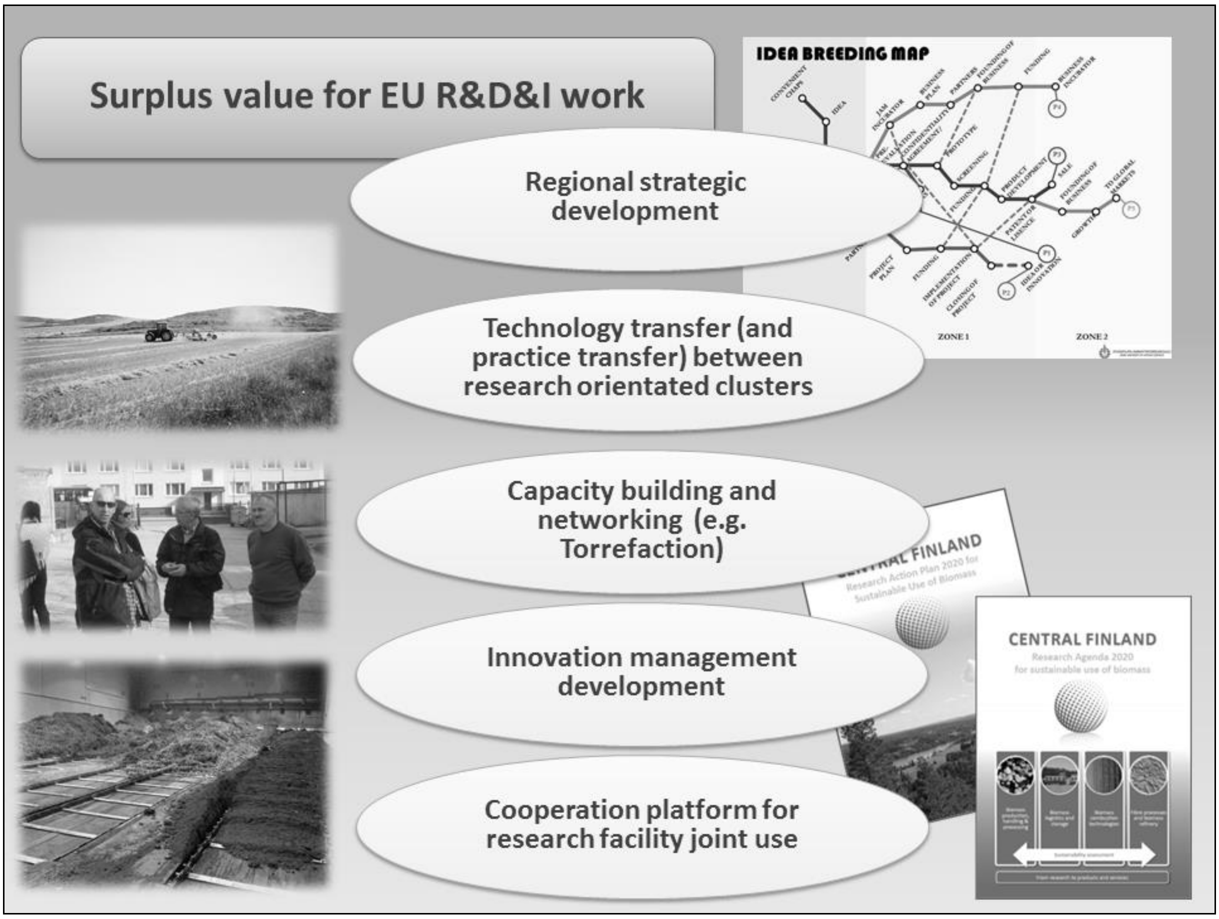
At European level BIOCLUS gave great input in technology platform work, especially for Renewable Heating and Cooling Platform. It offered an opportunity to learn about Horizon 2020 and prepare oneself for it. It supported many European networks by offering opportunity for participation and information dissemination, e.g. FEDARENE (European Federation of Agencies and Regions for Energy and Environment) cooperation and biomass related standard promotion. Furthermore the network development lead to new expertise networks that have already resulted for example Biodrying proposal within the FP7 framework programme.

The process has supported the joint use of research facilities by disseminating information about them and by introducing a model for the joint use of facilities. From a business point of view it supported international cooperation for the fuel biomass market. It increased technology transfer (and practice transfer) between research orientated clusters and between EU and USA as well as technology optimisation. Besides, the benchmarking visit to the USA gave extraordinaire opportunity for European experts, businessmen and decision-makers to learn about innovation management as well as initiative development.

In general, the surplus value for European R&D&I work was carried out with following steps:

- The partners participated and followed actively European innovation initiatives, for example in Renewable Heating and Cooling Platform
- It prepared the regional research driven clusters for new era of Horizon 2020
- It supported the participation, knowledge transfer and innovation management by networking and promoting expertise and competences
- BIOCLUS supported innovation management development e.g. at national level in Slovakia, at regional level in Navarra and at organisational level in Central Finland
- It offered an opportunity to have a more objective view on European R&D&I development by taking experts to the USA
- It was a possibility for technology transfer and practice transfer between research orientated clusters and between EU and USA
- Cooperation platform for research facility joint use at strategic and practical level (e.g. SUORA forest industry research …)
- It provided new knowledge based networks (e.g. in the field of torrefaction) and supported them to build new initiatives for FP7 and other programmes

The European benefits in nutshell are introduced in the following figure.



European level benefits of BIOCLUS in nutshell.

3.2 Additional value for the regional research driven clusters

The partners had an intensive three year period. The first half was concentrating on the regional strategic works. The second half has been JAP facilitation by concrete action improving the research capacities and networking. The cooperation will continue in forms of the joint actions that have been initiated during the project and have become possible due to BIOCLUS contacts. Besides, the new cooperation opportunities are under consideration. The additional value for BIOCLUS cluster has been analysed at European, regional, organizational and personal level. In practice in the Steering Committee meeting it was decided that the consortium will get together in autumn 2013 along the international bioenergy conference organized in Central Finland. The consortium will continue the cooperation in many fields.

3.3 Regional additional value in general

At regional level the project has produced valuable information in terms of analyses that were produced for the strategic works and for innovation environment development. For example in Navarra the process to provide the regional strategy for bioenergy and in Central Finland it supported the regional climate strategy work by providing background materials about biomass use and potential as well as and by offering expertise for setting the regional targets for bioenergy. The project has been a process to increase the regional cooperation and it has formed joint views for biomass related research cluster member. The organizations have been cooperating and committed in joint research focuses. Besides the research facility has developed. The mentoring and mutual learning of regions have been active and successful. There has been information and experience exchange as well as collaborative discussion between experts, authorities and business representatives.

The project has produced new initiatives at regional, national and European level. Also transatlantic cooperation has been strengthened. The JAP facilitation process has produced more than 10 new cooperation platforms, e.g. European Framework Programme. It has supported European torrefaction network development. The experts, authorities and business representatives have at once had exceptional opportunity to develop their capacities and networks. This has resulted great ideas and perhaps innovations.

In Central Finland, for example *Jyväskylä University* (JYU) and *VTT Finnish national research institute* (VTT) nanotomography co-operation continues as well as triple helix cooperation under Innovative cities initiatives. All regional BIOCLUS partners - *JAMK University of Applied Sciences* (JAMK), JYU, *Jyväskylä Innovation* (JI), *Regional authority Keski-Suomen liitto*, *Benet* company and VTT - are involved. The innovation environment has been developed at different levels in different clusters. For example in Central Finland the new concept to support potential and new entrepreneurs, Yritystehdas (Business factory) has been initiated. It is operated in cooperation with JAMK, JYU and JI/ Protomo.

The regional biomass use and potential up-dated analyses will be used in the climate strategy up-date work. Furthermore, *Centre for Research & Technology Hellas* (CERTH) and VTT has introduced topics for Renewable Heating and Cooling platform, such as Advanced Fuels (sustainable production of biomass feedstock for new bio-communities (thermally treated biomass e.g. torrefied biomass and pyrolysis oil) and Industrial heat (Agrobiomass cofiring) and for EERA Bioenergy cooperation. JAMK and the vocational school of natural resources (POKE) have agreed about future training cooperation in the field of Solid biofuels standards. The basis of this training is in cooperation with VTT experts that have been participating in the international standard group. The first training started in April 2013. The Central Finland JAP will be used in the further innovation work related to sustainability and biomasses, such as Innovative city initiative. In practice the cooperation continues also in the field of shared facilities in terms of

- JAMK/ VTT Expert services solid biomass boiler laboratory was initiated
- JYU/VTT nanotomography co-operation continues
- JYU/VTT Future fibre products development facilities co-operation
- JYU/VTT PhD-thesis of Janne Keränen: Increasing the drying efficiency of cylinder drying, where the potential of impingement drying for improving paper drying rate and quality were demonstrated
- JYU/VTT PhD-thesis of Antti Oksanen (December 2012), Improving the material efficiency of furnishes in papermaking by stratification and chemical modifications
- JYU and VTT nanotomography and dewatering cooperation continues. Cooperation includes measurement and modelling in these areas.
- JI and VTT: INT-Testaa intl. co-operation: Piloting possibilities to small and medium sized companies (SMEs) is offered. The previous TESTAA-project was launched to build up co-operation between the SMEs, large companies and research institutes in national level. In this concept SMEs proved the potential of their technology cost-effectively in pilot-scale papermaking environment.

Only own costs were expected to cover by SMEs. New SMEs were sought all the time from different business areas: process devices, measurement and sensors, materials, chemicals, modelling etc.

- During BIOCLUS-project VTT enlarged this work for international level in project called INT-TESTAA.

In Slovakia the project has initiated of intensive cooperation of relevant stakeholders on national level including national authorities, biomass and energy producers. It has established of the fruitful cooperation within Slovakia Research driven cluster as well as between European regional clusters in the field of Sustainable Use of Biomass Resources. Also the awareness within biomass resources sustainable use has increase in Slovakia. BIOCLUS elaborated feasibility studies within the biomass production and its supplies for the biomass producers in forestry, wood-processing industry and agriculture. The feasibility studies are elaborated also for the biomass energy producers in the field of supplies ensuring and biomass quality and production processes efficiency increase. The Self-Governing Region Banská Bystrica, Department of Regional Development and Working Group for support of biomass production and utilization, coordinated by the Ministry of Agriculture and Rural Development SR utilize the BIOCLUS results to extent cooperation. For example it has been used for the update of Slovakian national strategy of wood biomass production and utilization.

In Wielkopolska, cardoon will be implemented as a new and innovative biomass energy source for dry areas of Wielkopolska, especially re-cultivated land after the lignite mines' activities. Knowledge about cardoon was transferred from Western Macedonia to Wielkopolska during BIOCLUS project. New boiler will be designed or accommodated for cardoon firing. Promotional activities will be done towards increase in number of agricultural biogas plants in the Wielkopolska Region. Greenhouse gases emissions will be decreased by energy efficiency improvement in different energy consuming devices. BIOCLUS ideas will be implemented in practice. New projects will be generated.

At national level in Poland, biomass boilers design will be improved for higher energetic efficiency. Green certificates introduction will be promoted for heat energy production from biomass. Financial support implementation will be promoted for small biomass boilers in dependence from boiler power (smaller powers – bigger support). It should decrease investments costs of biomass boilers for end users. Also, it should enable boilers on fossil fuels exchange to biomass boilers. Based on BIOCLUS activities and achievements, there will be cooperation with Polish Ministry of Agriculture in the elaboration of support rules for biomass investments and their operation. New, innovative biomass logistic chains will be elaborated with BIOCLUS experiences application. There will be implemented in practice ideas from following documents elaborated in BIOCLUS SRA, JAP and Mentoring and Mutual Learning Plan.

In Navarra, due to the impact of BIOCLUS project in the near future different activities are going to be carried out in the region related to biomass. At regional level, after the approval in 2011, "Renewable Energy Technician" education level including biomass energy will be possible. Also BIOTERNA pellet production industry has started and will continue its EN+ Pellet certification. Besides, with BIOCLUS project it has been reached a cooperation relation between all the stakeholders of the region belonging to research, industry and administration. This relation has started during the project but will last in the next future. This fact will enable further capacity of biomass sector.

In the framework of the III Energy Plan of Navarra Horizon 2020, which takes into account bioenergy, both partners from the triple helix of Navarra, Government of Navarra and CENER are active part of the Joint Commission created in March 2013 by the Government of Navarra with the aim of promoting forest biomass in order to dynamise green economy and employment creation. The impact of this commission will be to increase forest related jobs in 1.650, reaching 5.650 jobs in around 300 companies (sawmills, logging companies, packaging, warehouse and manufacture). In Energy terms it is expected that biomass share in final energy consumption will increase from 3.9% in 2010 to 5% in 2020.

At international level, the European framework projects have been prepared and approved during BIOCLUS (SECTOR and LOGISTEC). The projects will make it possible to research deeply torrefaction and logistic issues related to biomass. Besides, ENERMASS from Interreg-SUDOE is now running for the creation of a transnational biomass cluster between regions of France-Spain-Portugal. Also, Navarra is participating on Bioenergy BESTF ERANET+, which will bring new opportunities to the region for the development of new biomass related research.

However, the creation of a formal regional cluster is still pending. Although the regional and consortium research lines in biomass are established in the JAP, a lot of concreted and special efforts must be done regarding this aspect.

In Western Macedonia the first step of the BIOCLUS strategy was to select the right members. This cluster is consisting of all types of partners (enterprises, educational organisations / research institutions and regional authorities) to achieve the specified goal. The **enterprises** got into the cluster bringing their experience of the market, the **educational organisations** used their experience to inform/train the employees of the enterprises, and the **research institutions** applied their high knowledge on biomass to solve important problems of the enterprises that do not allow them to increase their share in the market. In addition, the regional authorities provided all the other partners with information on available potentials, and through dissemination activities spread the outcomes of the project.

The experience of working in a team with companies of the same economic sector (on national and international level) increased extroversion and gave ideas for new collaborative work for industrial research and development projects, EU research funded proposals, sales of bundled products, etc.

Apart from that, the research institutions as CERTH and University of Western Macedonia (UoWM) got valuable information and experience within this project, regarding e.g. harvesting technologies, biomass characterization technologies etc. which were based on the capacity building.

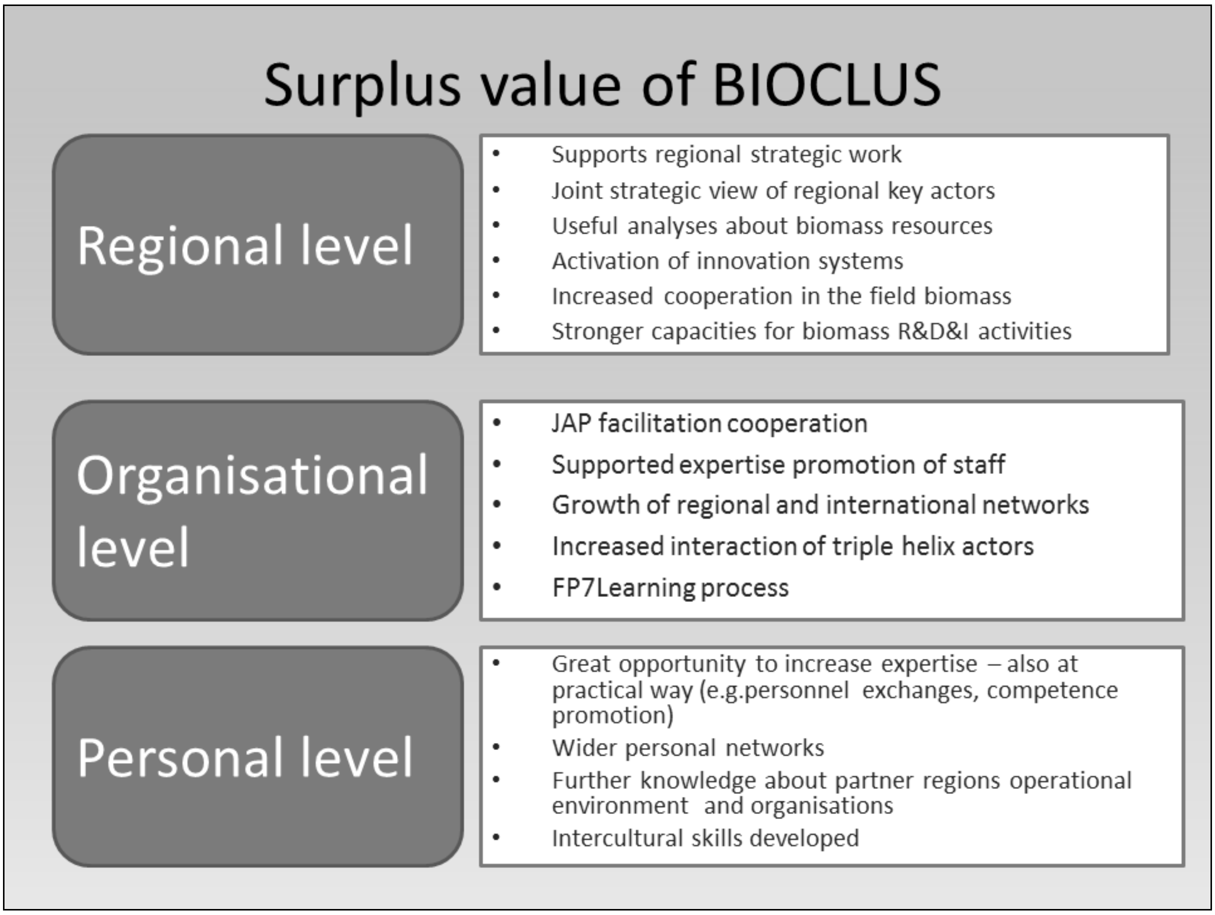
CERTH has strong ties with Greek and European stakeholders in the field of bioenergy, such as electric utilities, universities and research organizations, bioenergy associations and regional and national authorities. CERTH's researchers are involved in several national or European biomass associations and initiatives. These include the adoption of CEN 335 by the Greek Standardization Organization (ELOT), the Hellenic Biomass Association (HELLABIOM) and a leading position in the Biomass Panel of the European Renewable Heating and Cooling Technology Platform. PROFORBIOMED, a European MED Programme for the Promotion of residual forestry biomass in the Mediterranean basin is now running as well as FOROPA, a SEE programme for the creation of Sustainable networks for the energetic use of Lignocellulosic Biomass in South East Europe. Both projects are expected to bring new opportunities for research and transfer of good practices and know how.

3.4 Additional value at organizational level

At organizational level the project has supported strongly the strategic development process. It has facilitated the first steps identified in Joint Action Plan. It has supported the expertise promotion of research related cluster and supported interaction between triple helix actors. It has been a great learning process in Framework Programme world. Before the project the most of the partners didn't have experience about it. Now they are strongly prepared for Horizon 2020.

Furthermore, the personal processes have been in the focus. The project has facilitated large scale personnel exchanges. The people have built and strengthened their networks to peer-organisations at regional and international level. Besides, they have been able to cooperate with other kind of entities. For example the researchers have visited authorities and business cluster members, the authorities have learned from authorities in the different countries how to implement sustainability in strategic and practical level. The personal benefits have been networking and getting new competences and strengthening the old ones. Furthermore, the language skills as well as intercultural skills have been developed.

The details of the impact of project activities are introduced in the section "A description of the main S&T results/foregrounds" – along the description of the activity. In general level the impact of the project is introduced in the Figure 5 at cluster, organizational and personal level.



Impact of the project at cluster, organizational and personal level.

4 HIGHLIGHTS AND CONCLUSIONS

The partners had an intensive three year period. The first half of the project period was concentrating on the regional strategic works. The second half has been JAP facilitation by concrete action improving the research capacities and networking. The cooperation will continue in forms of the joint actions that have been initiated during the project and have become possible due to BIOCLUS contacts. Besides, the new cooperation opportunities are under consideration. The additional value for BIOCLUS cluster has been analysed at European, regional, organizational and personal level. In practice in the Steering Committee meeting it was decided that the consortium will get together in autumn 2013 along the international bioenergy conference organized in Central Finland. The consortium will continue the cooperation in many fields. The key impacts of the project are introduced in the Figure 5.

BIOCLUS provided regional benefits in environmental, economic and social terms. It developed the innovation system and increased the competitiveness of the BIOCLUS regions. It supported the European research area (ERA) and creation of European research networks in the field of biomass resources related sciences and supports sustainable and multi-functional use of biomasses. BIOCLUS enhanced the comprehensive understanding of regional biomass resources and promotes development, co-operation and integration of BIOCLUS cluster regions in the field of biomass resource related activities and innovation commercialization.

The concrete highlights of BIOCLUS processes are following:

- New biomass investment: Co-generation plan to Slovakia with the efficiency of 1.8 MW_e /1.2 MW_{th}. The company carrying out the investment is the partner in the project and got decision-making support through the project
- Networking and expertise exchange led to new R&D&I proposals at cluster and consortium level – the

cooperation continues in many projects and other intiatives

- Cardoon introduction to Wielkopolska region – it was learned in the study tour in Western Macedonia and studied by the Wielkopolska cluster member in the regional project
- Biomass is added in the 3rd Energy Plan of Navarra
- BIOCLUS analyses have been used as the background papers in the regional strategy development in all BIOCLUS regions
- Technology and practice transfer between research orientated clusters in Europe and between European Union and USA
- Regionally BIOCLUS supported regional competence promotion and other campaigns and concept development e.g. to convert heating from oil to renewable heating sources (small district heating networks and village schools).
- Commitment of organisations and staff - it is unusual to have 20 organisations in cooperation for three years with same key staff!
- Strategic processes were supported, e.g. Navarra got bioenergy strategy
- Intercultural skills were developed - be hard for a problem and soft for the people

The cooperation of research related cluster is based on the personnel level contacts as well as organisational level commitment

[1] L. Dinya, O. Brunet, B Callanan, J. Johnson, K. Knuuttila, Proceedings of 19th European Biomass Conference and Exhibition - Biomass and regional development (OD6.1-T5.6), (2011), p. 2465
[2] K. Knuuttila, A. Ylimartimo, H. Malinen, Case BIOCLUS, KEVAR-osaaja, http://www.uasjournal.fi/index.php/K-O/article/view/1285

FORESTENERGY2020 RESEARCH AND INNOVATION PROGRAMME

FORESTENERGY2020 - RESEARCH AND INNOVATIONS FOR A COMPLETE FOREST ENERGY CHAIN

Antti Asikainen[1] & Kai Sipilä[2]
[1]Finnish Forest Research Institute, Box 68, FIN-80101 Joensuu, Finland
[2]VTT, Box 1000, FIN-02044, VTT
antti.asikainen@metla.fi
kai.sipila@vtt.fi

ABSTRACT: METLA's and VTT's new 5-year research and innovation programme 'ForestEnergy2020' aims to open new paths to EU's renewable targets by producing research-based knowledge, technological solutions and service innovations for sustainable forest feedstock supply and conversion. The quantitative targets of the programme are ambitious: The fossil fuel inputs of the feedstock supply chain will be reduced by 30%, the cost of feedstock will be reduced by 30%, the added value of biomass based energy portfolio will be increased by 30%, and finally, the forest biomass based energy production will increase by 30TWh in Finland and 300 TWh in EU by 2020. The volume of the ForestEnergy2020 –programme is planned to be 50 M€ and 400-500 man years.

1 FOREST – LARGEST SOURCE OF RENEWABLE FUELS IN EU

Use of wood and wood waste for energy in EU totals 90 Mtoe annually representing almost 50% of all renewables. Currently, the the most remarkable biomass suppliers and end-users are the forest industries using the by products such as sawdust, bark and black liquor in energy production. District heating and combined heat and power production are also increasing the use on forest biomass as their feedstock. Several studies indicate that EU's forests could supply about 200 million m^3 (35 Mtoe) residual forest biomass and 100 million m^3 (17 Mtoe) woody biomass from urban areas, fence wood from farms and wood production on set aside land for energy.

Residual forest biomass (harvesting residues, wood from early thinnings and stumpwood) is already utilized in large scale in Sweden and Finland. About 16 million m^3 (2.5 Mtoe) forest biomass for energy production are utilized annually in more than 1,000 heat and power plants in the both countries. The main challenge in EU's forest biomass supply for energy is the mobilization of the existing forest biomass potential in a competitive and sustainable manner. Sustainable and reliable supply of feedstock will be a critical success factor for the long-term competitiveness of biomass-based energy production: Fuel represents typically 60-80% of the total energy production costs of a CHP plant.

2 CHALLENGES FOR DEVELOPMENT

2.1 New technologies and skilled labour for biomass supply and conversion

District heating and combined heat and power production using forest biomass as a feedstock is increasing rapidly and first commercial scale plants producing pyrolysis oil and bio diesel will start in a few years. The mobilization of new forest biomass resources in an efficient and sustainable manner calls for new technological solutions. Biomass supply chains have to be cost-efficient and sustainable also when supply stretches over very long distances. The manpower needed to run the operations is estimated to be over 40 000 machine operators in the EU. By now the entrepreneurs running round wood harvesting for industrial purposes have extended their operation to energy biomass supply. In the availability of skilled labor may become a serious bottleneck of supply.

New production and business concepts, where energy and energy carrier production is integrated with other industrial infrastructures show promising paths for resource efficient use of forest biomass. Particularly integration with the forest industrie's production systems is underway. Also traditional CHP sector already builds full scale demonstrations, where biofuel production or cooling of buildings is integrated in the existing services.

2.2 Economic sustainability must be improved

The ecological sustainability of increasing forest biomass harvesting has been studied intensively in the Nordic countries. A network of experimental sites was established over Finland and also experimental sites dating back to

1970's and 1980's have been revisited. Results show that the complete removal of the most nutrient rich tree parts (needles and fine branches) can diminish the growth of future tree generations. When the green biomass is left unharvested on sites and the coarse branches and stemwood are recovered, now growth impacts have been detected. In addition, impacts on ground and surface water as well as surface vegetation did not differ from the traditional wood harvesting.

The economic viability of biomass based energy, however, has been found to be the weaker link. Forest based bioenergy is competitive against oil in heat and power markets in many parts of the EU. As a result, thousands of heat and CHP plants using forest biomass as their main fuel have been raised across the EU. Replacing coal with biomass is more difficult and requires either taxation of coal or direct subsidies for biomass supply.

3 RESEARCH THEMES OF THE PROGRAMME

Research programme consists of seven thematic areas:

1. Sustainability of the biomass production, conversion and end use

   The main objective is to improve the knowledge on environmental, economic, and social impacts of forest biomass production, handling and conversion in order to assess the sustainable production and use of forest biomass objectively.

   Analyses build on the strong experience of Metla related to sustainable biomass production together with the strong experience of VTT related to biomass conversion technologies, deployment chains, and system level analysis.

2. Intensive production of woody biomass

   The main objective is to develop new methods for producing and harvesting energy biomass in dense deciduous forests and in dedicated biomass energy plantations. We will study and demonstrate establishment techniques, management alternatives, economy, and harvesting technology of these stands.
   - To develop and demonstrate cost-effective establishment methods of productive energy wood stands and to study their biomass production
   - To study the economy of intensive biomass production methods in dense downy birch stands and dedicated energy wood plantations
   - To study and improve the quality of wood fuel, harvesting technology, and procurement of biomass from dense, young deciduous forests
   -

3. Biomass resource assessment and feedstock availability

   Any investment decision or political target dependent on biomass supply should be based on a reliable estimation of available biomass resources. The objectives of the research topic are:
   - To support forest and energy industries and policy makers with biomass resource assessments,
   - To provide integrated biomass potential assessments and supply chain studies with the resource data
   - To integrate end-user structure and development of fuel demand with the assessments

4. Smart forest biomass supply chains

   The research area develops cost effective means of improving both quality of chips and functional reliability and efficiency of wood biomass procurement chains from forest to the end user by applying various supply solutions involving harvesting, storage, chipping, transportation and handling. The main objectives are to
   - increase the machine performance and efficiency by developing and testing new automation and feed-back system based solutions for forest energy supply chains.
   - develop prediction models and sensors for estimating the moisture content of stored woodfuel and apply these models to control systems in practice
   - develop better and more efficient storage and handling methods of woodfuel particularly at terminals where large amounts of wood can be handled and quality monitored more effectively
   - promote the efficient use of machine and driver resources by investigating cost effective means of multipurpose operation of prime movers and transportation equipment

5. Innovative CHPC (combined heat, power and cooling) production

The principal aims in short term are to create innovative solutions to increase the share of forest biomass fuels on existing power plants and to develop new technologies to improve loading factor of CHP production. The main tasks in short term are:

1. Upgrading existing power plant technology enable the use of biomass in co-firing with coal and in higher share of forest biomass fuels in co-firing with peat

- Commercialize of smart boiler concept for advanced multifuel operation – ensuring up to 20% increase to use of forest biomass fuels in existing power plants: Combustion additives, Fuel upgrading by utilisation of pellets, On-line boiler and operational monitoring tools to improve boiler performance, Integration of ICT knowledge and solutions on boiler and power plant technology

2. Roadmap work for extending the use of forest biomass fuels in energy infrastructure where the share of solar and wind energy will increase – the impact of intermittent production on CHP production using solid biomass

- Improving loading factor of CHP production by
  - Integration of cooling on CHP production
  - Integration of bio-oil or torrefied biomass production in existing plants
- Secure energy supply in private houses in new market situation
  - Smart small scale CHPC solutions for private houses and small communities by creating micro heating and cooling network utilising biomass + solar electricity and heating solutions + heat pumps
- Large scale city biomass CHPC concept for urban areas to maximize utilization of domestic biomass fuel resources

6. Biofuels for transport, bioenergy carriers and biorefineries

The objective of this research topic is to develop and analyse new concepts for increasing the wood energy business to complement existing business sectors and to utilise the potential of integration benefits maximally. The main tasks are

- To develop gasification-based BTL technologies which will have maximum overall biomass utilisation efficiency, lower capital costs than present processes and which can be realised in intermediate size range with full integration to forest industries and/or district heating
- To upgrade fuel quality of bio-oil in a manner making it possible to replace light fuel oil in existing or slightly modified boilers, power plant engines, and eventually to co-feed it into mineral oil refineries
- To continue the development of both techincally and economically efficient fraction methods for hemicellulose and cellulose separation from biomasses for hydrolysation and fermentation processes in different scales as well as to produce sulphur free lignin for combustion and other uses
- To carry out techno-economic and sustainability studies on different biomass-conversion and utilisation routes

7. FIN/EU 2020 & 2050 low carbon bioenergy scenarios and implementation paths

We elaborate and investigate long term scenarios for supply of and demand for woody biomass for energy and material uses from national to global levels.

The main tasks are:

- To develop and apply technology rich integrated assessments models on bioenergy sector,
- To create scenarios for the development of the user structure including novel uses of biomass,
- To evaluate the efficiency of alternative policy measures aiming at increased use of biomass in the energy sector,
- To examine the market impacts of the increased use of bioenergy

4 AMBITIOUS 30-30-30-30 TARGETS

ForestEnergy2020 aims to open new paths to EU's renewable targets by producing research-based knowledge, technological solutions and service innovations for sustainable forest feedstock supply and conversion. The programme aims high: The fossil fuel inputs of the feedstock supply chain will be reduced by 30%, the cost of feedstock will be reduced by 30%, the added value of biomass based energy portfolio will be increased by 30%, and finally, the forest biomass based energy production will increase by 30TWh in Finland and 300 TWh in EU by 2020. The volume of the ForestEnergy2020 –programme is planned to be 50 M€ and 400-500 man years. More information and results of the programme can be found from www.forestenergy2020.org.

SPATIAL ANALYSIS OF THE REGIONAL BALANCE OF POTENTIAL AND DEMAND OF FOREST CHIPS FOR ENERGY IN FINLAND

Perttu Anttila, Mikko Nivala and Juha Laitila (*corresponding author)*
Finnish Forest Research Institute,
P.O.Box 68, 80101 Joensuu, Finland
firstname.lastname@metla.fi

Abstract:

By 2020, Finland should use annually 13.5 million solid cubic metres (Mm^3a^{-1}) of wood chips in CHP production and separate heat production. Earlier estimates have shown that the techno-economic potential is higher than the objective on the national level. However, on some regions the demand is higher than the supply and vice versa. Therefore, persons planning a plant investment or the ones responsible of feedstock procurement would benefit from a balance map of forest chip potential and demand. It is also important that the underlying assumptions of the potential estimates are feasible and up to date. The objectives of this study were to update municipality-level potential estimates for forest chips and to assess the regional balance of potential and demand of forest chips in Finland.

As crown and stump biomass are side-products of harvesting of industrial roundwood, the potentials of crown and stump biomass from final fellings depend on the level of saw timber harvests. The potentials were calculated to represent average harvest levels of the past ten years and the levels of the highest and lowest harvests. The biomass potentials of small-sized trees from early thinnings were based on National Forest Inventory data. For small trees, alternative estimates were calculated for harvesting of stem only, harvesting of whole trees and integrated harvesting of industrial roundwood and energy wood. On the national level, the annual potentials of crown biomass varied from 4.0 to 6.6 Mm^3a^{-1}. Correspondingly, the potentials for stumps varied from 1.5 to 2.5 Mm^3a^{-1}. For small trees, the potentials reached from 6.2 Mm^3a^{-1} for stem only to 18.8 Mm^3a^{-1} for integrated harvesting.

For the spatial analysis the plants utilising forest chips were digitised and for each plant a supply region depending on the consumption determined. The balance maps revealed that there is a region in the western coast where there is no extra potential of crown biomass in high demand for saw timber. In the case of low demand the region expands to central Finland. For stump wood the region is even larger including almost the whole of northern Finland. However, the balance for small trees is generally positive, especially if procured as integrated with industrial roundwood. Therefore, in order to meet the national targets more emphasis should be put on increasing the profitability of harvesting small trees and developing logistics of crown and stump biomass.

FLUIDISED BED TECHNOLOGY ENABLING COMPETIVE USE OF WOOD FUELS FOR HEAT AND POWER

Aho M.
VTT Technical Research Centre of Finland
P.O. Box 1603, FI-40101 Jyväskylä, Finland
martti.aho@vtt.fi

ABSTRACT: Wood fuels enable CO_2-free energy production, but safe use of wood at high energy portions in power plants needs experience to avoid superheater damages. As presented earlier, one possibility to minimize risks is to calculate certain indexes from the elemental composition of the fuel (molar S/Cl etc.) but low concentrations of these elements in wood (close to detection limits of analysis) increase uncertainty of these indexes. Another way is to make experiments to determine the limit portion of wood needed to start Cl deposition on superheaters or even try to measure the corrosive gas components directly to know the maximum safe portion of wood in co-firing with fossil fuels or alternatively to fire bare wood with protective chemicals.

Keywords: Power plants, Forest biomass, Corrosion

1 INTRODUCTION

In addition to wood, 23.5 TWh coal and peat was used in combined heat and power production (CHP) in Finland in 2011 [1]. A significant portion of coal was fired in the pulverized fuel power plants on the Finnish coast. The energy content of peat and coal used in CHP in Finland in 2011 corresponds to about 12 million solid m^3 (Mm^3 s) wood. For example, in the large fluidized bed power plants located at Finnish cities of Jyväskylä, Kuopio, Oulu, Mikkeli and Pietarsaari wood has already been burnt at relatively high portions together with peat and (or) coal, and the goal is to increase further the energy portion of wood in those power plants. This trend is due to restrictions in peat production, CO_2 taxation, political pressure etc.

About 58 Mm^3 s raw wood was harvested from Finnish forests in 2011. In addition, about 10 Mm^3 s raw wood was imported. Paper and cellulose industry used 37.5 Mm^3 s , timber industry 21.3 Mm^3 s and board and product industry 3.0 Mm^3 s, 61,7 Mm^3 s altogether. In addition, 5,4 Mm^3 s stem wood was used to space heating for small houses [1].

To replace coal and peat totally by wood in CHP production would require the above mentioned 12 Mm^3 s extra wood. To get this wood quantity in short term is very challenging. In addition, massive investments to the power plants might be necessary, although partly completed, such as increasing the capacity of the wood feeding line(s), enabling additive feeding to the furnace etc. Anyway, the portion of wood will be further increased in the power plants co-firing wood with fossil fuels (for example, in the fluidized bed power plants of the above mentioned Finnish cities). Peat will be partly replaced with coal also, if conditions to peat production will become more difficult (due to legislation, restrictions to get licenses to new peat production areas, etc.).

The largest sources of non-waste-based biomass to CHP plants in Finland are soft-wood originated forest biomass as a by-stream of wood production for paper manufacturing. Their chlorine originates mostly from needles and bark [2], but due to lack of elements protecting power plant superheaters against chlorine-corrosion even very low Cl concentrations cause fouling and corrosion of superheaters in effective power plants (Tsteam >450 ^oC). These problems, which can lead to expensive superheater damages, were not expected, and the high portion of peat protected earlier the superheaters. Recent experiences especially with 100% forest biomass have, however, revealed the high corrosion risk.

The protective effect of peat and coal against the chlorine induced superheater corrosion can be due to sulphur and aluminum silicates. Both of them can destroy alkali chlorides (Eqs. 1 and 2) before their condensation on superheater tubes. However, the power of aluminum silicates can be insignificant with peat. Presence of alkali chlorides in superheater deposits can start corrosion (Fig. 1)

SO_3 +2 KCl + H_2O -> K_2SO_4 + 2 HCl
/1/ [3]

Al_2O_3 * 2 SiO_2 + 2 KCl + H_2O -> K_2O * Al_2O_3 *2 SiO_2 + 2 HCl /2/ [4]

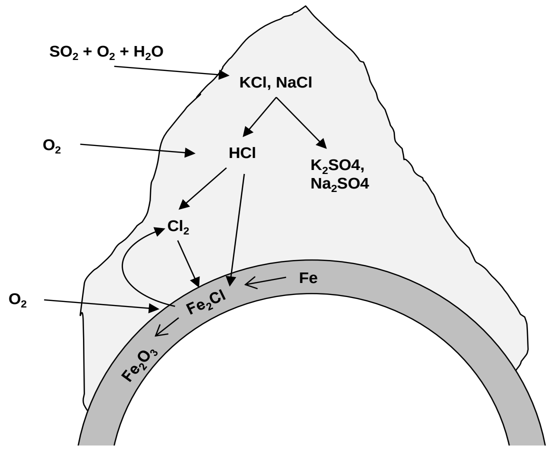


Figure 1. Illustration of chlorine originated superheater corrosion after Cl- condensation in the superheater deposits in form of alkali chlorides [5].

The role of fluidised bed combustion is essential in large-scale CHP production from wood fuels blended with peat and/or coal. Grate power plants are typically smaller, and fuels with very different combustion properties are difficult to co-fire in these plants. Pulverised fuel power plants are usually fired with coal and are typically too large to enable high portions of biofuels in blends with coal.

2 RESULTS FROM EARLIER CALCULATIONS OF MAXIMUM SAFE PORTION OF FOREST BIOMASS IN BLENDS WITH PEAT AND COAL

VTT presented earlier [2] some results from calculations of maximum safe energy portions of wood fuels in fluidised bed power plants when blended with peats and coal. Those results based on molar S/Cl and molar (2S+Al)/Cl ratios calculated for the blends (table 1). All these fuel samples were analysed in VTT's earlier projects before year 2000, where also experimental work at fluidised bed combustion conditions was carried out in co-operation with Finnish industry [5]. The values of these indexes decrease with increasing portion of forest biomass in the blend. The results from combustion experiments combined to analysed fuel compositions suggested the following minimum values to the indexes: S/Cl $\approx$ 3 and (2S+Al)/Cl $\approx$ 14. These boundary values were applied to determine the maximum safe portion of wood fuel in some new blends. The calculated safe upper energy portion of wood fuel varied between 42 and 94%. Co-firing wood with a coal sample and with a sulphur-rich peat sample enabled largest safe wood portions (75-95% of energy). Instead, co-firing fossil fuels with pine bark (containing 0.05 wt% Cl) gave lowest values for safe wood portions (42-68 of energy). The main source of Cl to this bark might have been the de-icing salt used on the highways (due to contamination during truck transport).

The composition of the fuels used to calculations are shown in table 1 [2].

Table 1. Compositions of some wood and fossil fuel analysed in 1998-1999

Fuel	Spruce bark	Forest residue	spruce chips	pine bark	peat 1	peat 2	peat 3	coal
Ash (815 °C), wt%	2.0	2.2	2.2	2.0	4.2	5.1	9.5	16.1
LHV, MJ/kg	18.9	19.5	18.7	20.0	21.0	22.4	20.2	27.8
S, wt%	0,020	0,030	0,020	0.040	0.16	0.31	0.66	0,59
Cl, wt%	0,02	0,02	0,02	0.05	0.03	0,022	0,03	0,03
molar S/Cl	1,1	1,7	1,1	0.9	3.2	9,7	47,4	21,7

3. RECENT ACTIVITIES IN VTT (TOGETHER WITH INDUSTRY) TO IMPROVE ACCURACY TO ESTIMATE THE UPPEST SAFE ENERGY PORTION OF WOOD IN CHP PRODUCTION WITH FLUIDISED BED COMBUSTION TECHNOLOGY

A combustion study with pilot-scale fluidised bed reactors using wood fuels blended to peat and coal was going on in winter and spring 2013. The fuels were carefully analysed before the combustion experiments. Comparison of the earlier analysis data (table 1) to the recent data (table 2) enabled to make some observations:

Probably the precision of chlorine analysis has been improved during the last 15 years. Before the year 2000, concentrations of Cl in wood were usually given with one significant number (for example 0.02 wt% instead of 0.020 wt%) and the obtained values were higher than in 2013. For example, surprisingly high Cl concentration was measured for spruce (as whole tree chips) in 1998 (table 1). According to the new data, even forest residue contained less Cl (the maximum concentration of Cl measured for forest residue samples was 0.017 wt.%, see table 2). The indexes based on concentrations of Cl and S are very sensitive to the analysis results (compare the values of S/Cl indexes for wood in tables 1 and 3). Supposing that the obtained analysis results were systematically slightly too high for Cl before year 2000, the value to the S/Cl ratio suggested earlier to correspond to the maximum safe portion of wood in the blend (molar S/Cl ≈ 3) is too low, correspondingly. Actually, S/Cl was > 3 even in 100% wood fuel in most cases in table 2. So, a new boundary value to determine the a safe blend should be found (based on results from combustion tests with deposit collection etc. and improved accuracy of Cl analysis from wood fuels).

Sulphur content in wood can be sufficiently high to give some importance to reaction 1. S/Cl is 3.2 both for wood blend “60/40” and for forest residue no. 2 with twice as much Cl. Proving similar Cl deposition power between those two wood fuels needs measurements of Cl deposition at superheater conditions either in pilot plant or in power plant scale.

Table 2. Analysed compositions of some wood fuels and fossil fuels analysed recently

Fuel	Stem wood chips	Forest residue 1	60/40 blend	Forest residue 2	Finnish peat	Russian coal	S-A coal
Ash (550 ºC) wt%	1.1	3.7	2.1	4.6	10.2	11.4	16.1
Ash (815 ºC), wt%	0.9	3.3	1.9	4.3	10.1	10.9	15.4
LHV, MJ/kg	19.35	19.33	19.34	19.54	19.62	29.19	27.8
C, m-% k-a	49.8	49.9	49.8	51.5	50.9	72.3	70.4
H, m-% k-a	6.2	6.0	6.1	6.0	5.5	5.1	3.95
N, m-% k-a	0.32	0.47	0.38	0.64	2.16	2.24	1.61
S, m-% k-a	0.020	0.030	0.024	0.05	0.22	0.30	0.59
Cl, wt%	0.006	0.012	0.0084	0.017	0.025	0.007	0.030
molar S/Cl	3.7	2.8	3.2	3.2	9.7	47.4	21.7

To go on in this topic, experimental work was carried out with wood fuels shown in table 2 as such and blended with peat and coals shown in the same table. Both VTT's 20 kW bubbling bed reactor (shown in Fig. 2) and VTT's 60 kW circulating bed reactor (shown in Fig. 3) were utilized. One way to measure the safe upper limit for wood biomass in blends with peat and coal was to determine the limit to Cl deposition at superheater simulators (Fig. 4). Also other methods (not shown here) were used.

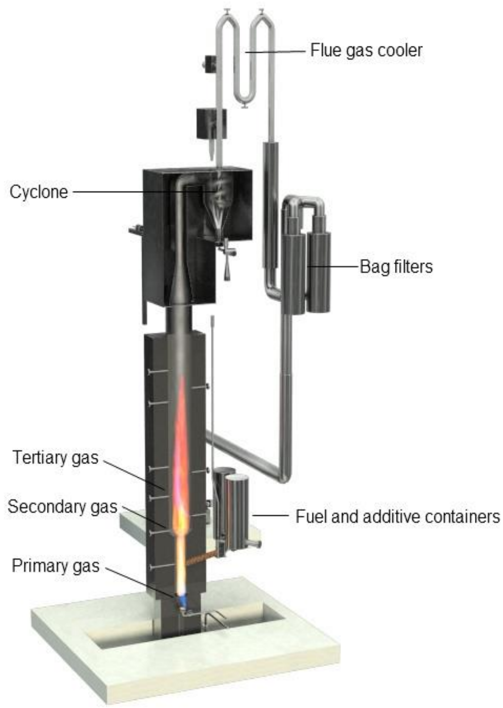


Figure 2. VTT's 20 kW bubbling bed pilot plant

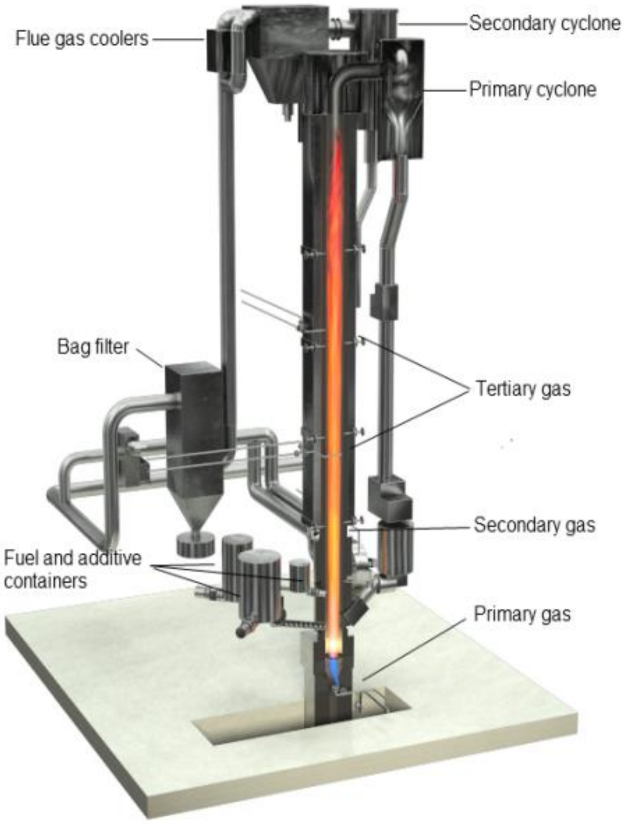


Figure 3. VTT's 60 kW circulating fluidized bed pilot plant

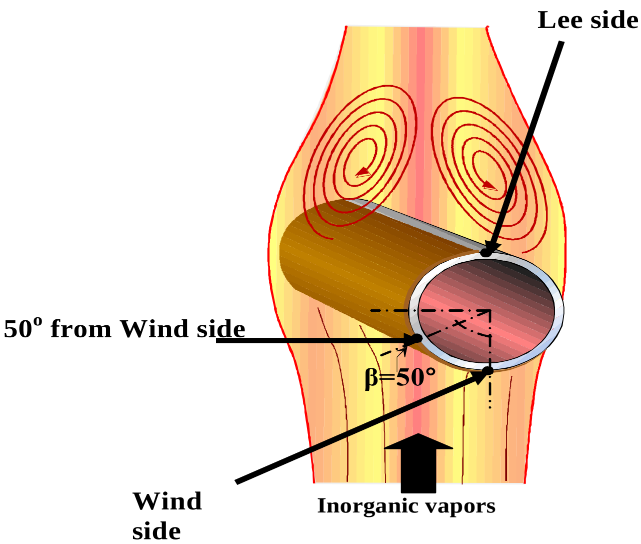


Figure 4. Collection of deposits to simulators (with metal and flue gas temperatures simulating conditions at critical superheater zones) and typical sites to elemental analysis (for example Cl as wt% in deposit).

4 CONCLUSIONS

The experimental work with pilot-scale fluidised bed reactors (Figs. 2 and 3) including deposit collection and analysis (Fig. 4) etc. during winter and spring 2013 revealed the following main things:

- Wood fuels can be combusted safely with fossil fuels even at portions of > 70 % in energy (depending to the composition of the components in the blend). So, the information given earlier (for example in Bioenergy from forest 2012 conference [2]) was not misleading in that viewpoint. On the other hand, and with help of the results from the experimental work done in 2013 and improved accuracy of Cl (and S) analysis from the wood fuels, one can conclude, that the minimum safe value to molar S/Cl of the blend suggested earlier (S/Cl ≈ 3) is too low. The better value is between 4 and 5, but pilot-scale tests are warmly recommended before increasing the energy portion of forest biomass in power plants.
- Sulphur even in wood can have protective power against Cl deposition. This was shown by similar Cl deposition power of forest residue 2 compared to wood blend “60/40”. Value for S/Cl index was equal (3.2) in these fuels but the sample “Forest residue 2” contained twice as much Cl as sample “60/40” (see table 2).
- Set of pilot plant tests give theoretical maximum to the energy portion of wood in its blends with different peats and coals. To get the real maximum to a particular power plant, the uncertainty to control and know the blend composition at the power plant should be taken into account. For example, if the theoretical maximum (from pilot plant research) is 82% wood in energy for a particular wood mixed with a particular peat, and the sum of uncertainty to know the exact blend composition (including errors of blending at the power plant, fluctuations in fuel delivery etc.) is 12%, the real maximum to that power plant is 82-12 = 70 % wood in energy for that blend.

5 ACKNOWLEDGEMENTS

Funding from energy producing and power plant manufacturing industry is gratefully acknowledged.

BIOMASS RESOURCES AND PRODUCTION

ORGANIC WASTEWATERS AS A GROWTH MEDIUM FOR ALGAL MASS CULTIVATION

Kalle Valkonen, Marika Tikka, Anne Ojala, Martin Romantschuk*
University of Helsinki, Department of Environmental Sciences
Niemenkatu 73, 15240 Lahti, Finland
kalle.valkonen@helsinki.fi, marika.tikka@helsinki.fi, anne.ojala@helsinki.fi, martin.romantschuk@helsinki.fi
**Corresponding author*

Algal oils and biomass have been seen as promising candidates for next generation biofuels replacing the food crops based biofuels. The estimated annual production schemes show tremendous numbers due the calculations based on lab scale tests and theoretical yields. However the current LCA analyses show that algal biofuel production still consumes more energy than is produced. One key component of the energy consumption is the use of inorganic nutrients for algal cultivation. In Aldiga, a Tekes funded project we investigated the possibility of integration of algal biofuel production to the existing treatment of organic wastewaters.

In natural waters, the main nutrients (N, P) are usually the growth limiting factors for green algae. However when algae are cultivated for biomass production purposes the requirements increase for micronutrients and trace elements as well. We hypothesize that the minimal factors in wastewaters used as basis for algal cultivation might be other than the main nutrients. Our objectives are (1) to test the suitability of the wastewaters for algal cultivation; (2) identify the true minimal factors to optimize the growth medium composition.

The tested wastewaters were highly concentrated originating from leachate of newly collected municipal and industrial biowaste prior to composting and the reject water of anaerobic digestion of swine manure and industrial biowaste. Reject water and biowaste leachate had very high organic load, COD_{Cr}, 20 000 and 80 000 mg O l^{-1} respectively. The main nutrient contents in reject water and biowaste leachate were 3860, 3150 mg N l^{-1} for total N and 3800, 1650 mg N l^{-1} for ammonium and 540, 200 mg P l^{-1} for total phosphorus respectively. The strain *Chlorella sorokiniana* UTEX 1230 was cultivated in wastewaters diluted (1:10 for reject water and 1:20 for biowaste leachate) with distilled water in illuminated 5 L laboratory bioreactor. The nutrient composition and elemental analysis from filtered cultivation water was carried out four times during the experiment together with algal biomass assay. The highest reached algal biomasses in the 8 day experiment in biowaste leachate and reject water were 743±24 and 430±17 mg DW l^{-1} (n=3) respectively.

To recognize the minimal factors of the wastewaters the water analysis data were compared with the literature based elemental composition of green algae. Biomass capacity (g L^{-1}) was calculated by division of the concentration of element present in wastewater (g L^{-1}) with elemental concentration in model green algal biomass (g g^{-1}). This analysis was made separately to each element (N, P, K, Mg, Ca, Fe, Mn, Zn, Cu, Co, and Mo). Analysis revealed that the compost leachate was rich in all the micronutrients and the first element to limit growth would be nitrogen and second phosphorus. In compost leachate the calculated biomass capacity for other elements ranged from three to over one hundred fold compared with phosphorus. On the contrary reject water had high biomass capacity of N and P compared with Mg, Mn, and Ca. Mg was the only element that was completely depleted during the cultivation. Additionally we observed increasing amounts of some metals (Cr, Fe, Mo, Ni) in wastewaters, and P, Al and Zn from biowaste leachate only during the cultivation. This was due to the particulate characteristics of the wastewaters and desorption of the molecules from particles to liquid phase through oxidative processes during cultivation.

The biowaste leachate was a better substrate for algal cultivation. However, it would benefit from the addition of the main nutrients and on the other hand the reject water could be used as a source of the main nutrients but showed incompetency as the only source of nutrients in algal mass cultivation. when reject water was only used as a source of the main nutrients he nutrient reduction and algal biomass production was equal to biowaste leachate. The experiment revealed the inadequacy of analysis of the main nutrients only to estimate the suitability of wastewaters for algal cultivation. Heavy metal concentrations in wastewaters and algal biomass needs to be monitored to make sure that the concentrations do not exceed toxic thresholds for cultivated algae or the desired product.

DEVELOPMENT OF ENERGY WILLOW AND USE IN FINLAND

Leinonen A [1], Sihvonen J [1], Kärki J [1], Hurskainen M [1], Villa A [2], Kaipiainen E [2], Janhonen P [3], Joensuu I [4] and Reinikainen O [5]

[1] VTT Technical Research Centre of Finland, [2] University of Eastern Finland, UEF, [3] The Vocational Education Institute of Northern Central Finland, POKE, [4] Finnish Environment Institute, SYKE and [5] Vapo Oy

[1]Koivurannantie 1, 40100 Jyväskylä,[2] Yliopistokatu 2, 80111 Joensuu, [3] Uuraistentie 240, 43130 Tarvaala, [4] Yliopistonkatu 7, 80100 Joensuu, [5] Yrjönkatu 42, 40100 Jyväskylä

arvo.leinonen@vtt.fi, jori.sihvonen@vtt.fi, janne.karki@vtt.fi, markus.hurskainen@vtt.fi, aki.villa@uef.fi, erik.kaipiainen@uef.fi, pekka.janhonen@poke.fi, ilona.joensuu@ymparisto.fi and olli.reinikainen@vapo.fi

ABSTRACT: The three years' willow project was launched by VTT, UEF, POKE and SYKE in 2011 in Central Finland and in North Karelia. The aim of the project is to develop the production and use of willow biomass for energy and to decrease the water emissions in Finland by using willow plantations. Research scopes are the establishment of willow plantation; cultivation, harvesting and combustion of willow; the use of willow in small-scale biodiesel production and the use of willow plantation in the purification of different types of polluted water. The business opportunities and potential for willow growing in Central Finland and North Karelia is also evaluated in the project. The production costs of willow chips and the use of willow plantation for the water treatment will also be calculated.

Finland has currently 50 – 100 ha of short rotation willow coppice plantations and there is a large potential for growth on a set aside or marginal agricultural land, cut-away peatland and buffer strips on farmland.

During 2011 – 2012 four new willow plantations have been established: three in Central Finland and one in North Karelia. Two of the new plantations in Central Finland have been established on peatlands and one on farmland. The main target of the plantations is to investigate the use of willow plantations to decrease the water emissions from peat production area in addition to the biomass production of plantation. The willow plantation in North Karelia was established beside the water treatment facility of the Outokumpu town in order to investigate the use of willow plantation to purify the pre-treated process water coming from the treatment facility. The water treatment research on the willow fields started in summer 2013.

The plantations established in the project have been fertilized with different types of by-product fertilizers such as combustion ash, waste water sludge and runoff water from agricultural land and peat production areas. Locally suitable willow clones (*Salix schwerinii*) have been used in establishment.

Willow harvesting trials were carried out in May 2012. The main aim in the trial was to test how efficiently and at what cost can willow be harvested with machinery already available in Finland. In the trial, willow was harvested as stems using a forest equipped agricultural tractor with an accumulating harvester head. The stems were transported by tractor trailer to the roadside. About 200 solidm^3 of willow stems was harvested in the trial. Harvesting costs can be lowered significantly by using a specialized whole tree harvester head, but this requires an annual harvesting area of 200 ha for economic use.

Combustion tests were carried out with a Pilot scale BFB-boiler in November 2012. Willow chips in the pilot tests did not differ from other whole tree chips. The tests results are in line with Polish experiences gained during a study visit. Large scale tests were carried out in February 2013 in Fortum's district heating plant in Joensuu. Based on the project results willow seems to be quite attractive fuel combustion wise.

Keywords: willow, cultivation, energy, water purification

2 INTRODUCTION

At present there are only 50 – 100 ha of willow plantations in Finland. The objective of the three year research project "Sustainable harvesting and utilisation of energy willow", started in 2011 by VTT Technical Research Centre of Finland (VTT), University of Eastern Finland (UEF), the Vocational Education Institute of Northern Central Finland (POKE) and Finnish Environment Institute (SYKE), is to promote the utilisation of willow in energy production and for purification of different kinds of waters. The main objectives of the research include the establishment of a willow plantation, the utilisation of the willow plantations for purification of the run-off waters of peat production areas, utilisation of the plantations for purification of the process waters of waste water treatment plants, harvesting of willow for fuel, combustion of willow, and the utilisation of willow for manufacture of biodiesel. Additionally, the harvesting potential, and different production and utilisation concepts of willow are investigated.

Sweden and Poland are forerunners in utilisation of willow. In these countries willow has been used especially for energy use. In Sweden, the willow cultivation area is about 15 00 ha, and 6 000 ha in Poland. Good experiences have been obtained in Sweden from the utilisation of willow plantations by the side of waste water treatment plant. In Poland, the willow is used as fuel e.g. in the Czestochova CHP plant owned by Fortum. The fuel power of the plant is 206 MW_{th}. The main fuel of the plant is coal. On the basis of the good experiences in utilisation of willow, it has been possible to increase the share of willow into

20% of the energy. The willow chip harvesting costs of a chipper-harvester is 11.5 €/MWh at the roadside (Figure 1). The price of the willow chips at the plant is 18 – 21 €/MWh. In Poland, the average annual harvest of willow is 8 – 10 tons/ha, and 6 – 12 tons/ha in Sweden.

Cut-over bogs, fields poorly suitable for other cultivation, and the fields removed from agricultural use form the major potential areas for cultivation of willow in Finland. At the areas of Northern Karelia and Central Finland, which participated in this research, the amount of potential willow cultivation area is several thousands of hectares.

Figure 1. Harvesting of three to four years old willow in Poland with a chipper-harvester in winter 2012.

3 ESTABLISHMENT OF A WILLOW PLANTATION

In total four willow plantations were established in the project during 2011 and 2012. The total area of the established plantations is 7,5 ha. The establishment of a willow plantation and the establishment costs of them were studied especially in the plantation of Savonneva mire in Kyyjärvi, established in the spring 2011. The plantation has been established at the cut-over peat production area. The objective of the research, carried out at the plantation, is to study the applicability of the willow cultivation for the after-use of cut-over peat production areas. The area has mainly been used for investigation of the effects of fertilisation and the willow species in the growing of willow on the peat-base.

The total area of the willow plantation established at the Savonneva mire is 3,2 hectares consisting of six peat production strips removed from peat production. Four different willow clones, a Russian origin *Salix schwerinii*, a Finnish origin *Salix myrsinifolia*, and Sweden origin hybrids Klara and Karin, were planted at the plantation. The plantations were established using three different types of fertilisation combinations. The combinations included: (1) Pellon Y6 fertiliser and lime, (2) biotite and liquid manure, and (3) ash and liquid manure. Ash and liquid manure combination had best nutrient supply properties.

The test areas were prepared for production by determining first the nutrient contents and pH. The fertilising requirement of the areas, based on the different fertiliser mixtures, was determined. The first working phase included dragging, in which the thickness of the peat layers of the strips were levelled. After dragging the fertilisers were spread on the field. The fertiliser, the peat layer and the mineral soil were mixed together by ploughing. The ploughed area was tilled using a toothed harrow, after which the test area was ready for plantation of the willow cuttings into the field. This was carried out using a Swedish planter, which uses 25 cm long cuttings. The planting machine was not suitable for peatlands, due to which the cuttings had to be planted by hand into the soil by sitting on the machine. The planting density of the cuttings was 15 000 cuttings per hectare. The cuttings were planted into paired rows, in which the distance between the rows was 0.8 m and the distance between different row pairs 1.5 m.

Average plantation establishment costs were calculated on the basis of the results. The realised costs at the Savonneva mire, however, exceeded the average real costs, because soil tillage and spreading of the fertilisers could not be carried out as efficiently as possible. The equipment was not suitable, and the transportation distances of the equipment to the Savonneva mire were relatively long. The real costs at the Savonneva mire, in respect to the fertilising, were about 4 500 €/ha. By operating as effectively as in agriculture and by using a new planting machine, it is possible to reduce the plantation establishment costs by 44 – 50%. By taking the utilisation time of the cultivation and the additional fertilisation into account, the establishment costs of a willow plantation vary in between 3.2 – 4.8 €/MWh, if the working phases can be carried out efficiently. In the calculation the annual biomass production was 11 tons/ha, the harvesting cycle five years and the age of plantation 20 years. The establishment costs are comparable to those obtained in Sweden. The largest costs of establishment of a willow plantation are the willow cutting prices, corresponding to 51 – 54% of the total costs.

The measurements carried out in autumn 2011 and in 2012 (Figure 2) showed that the establishment of the plantation was successful. Growing of the willows has started well and the mortality of the cutting at the area was relatively low.

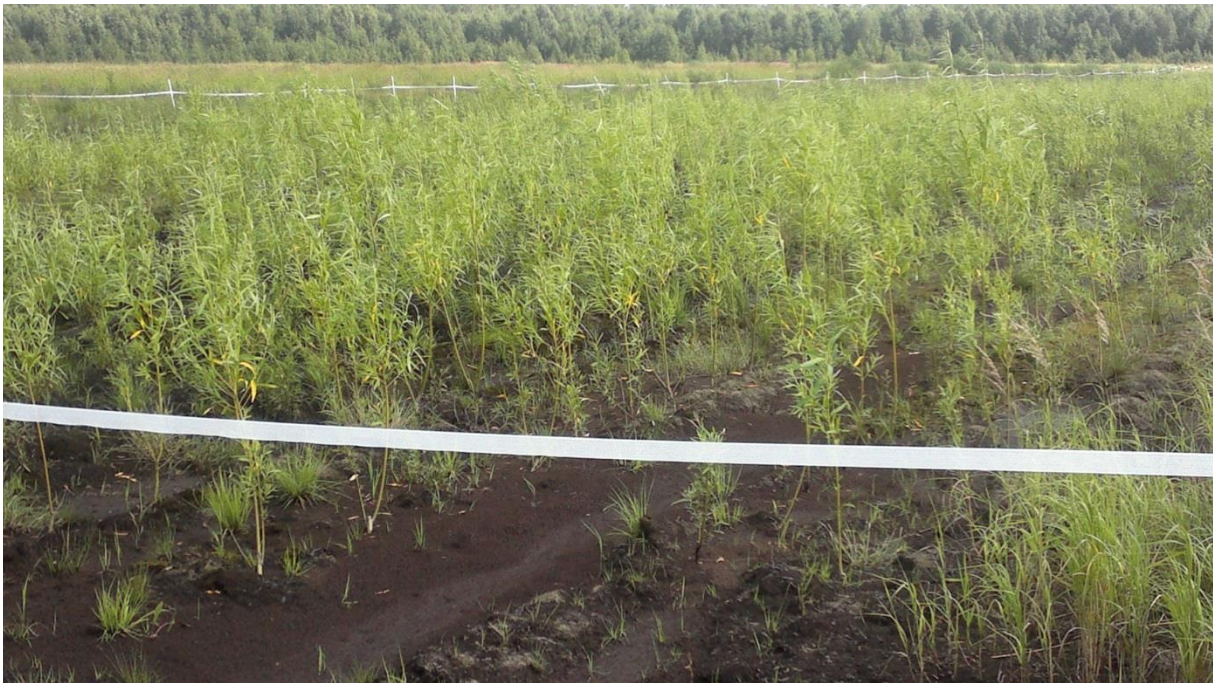


Figure 2. Savonneva willow plantation in the summer 2012. The area is protected with an elk-fence.

4 PURIFICATION OF THE RUNOFF WATERS OF PEAT PRPODUCTION AREAS

The willow cultivation field was established in the spring 2012 at the Raatteikonsuo peat production area of Vapo Oy. The objective is to study the utilisation of a willow plantation for purification of the drainage waters of a peat production area. Good results have been obtained in Sweden on utilisation of willow plantations for reduction of the phosphorus and nitrogen contents of the process waters from waste water processing plants.

About 1.3 ha of willows was planted on one of the wetland areas of the Raatteikonsuo. 2.0 ha of the wetland area were left alone to be used as a reference area, on which no cultivation was formed. The drainage area of the total wetland area is 62.7 ha. From the drainage area 42.8 ha is under peat production. The willow cultivation area was separated from the reference area by an embankment. Purification of the run-off waters of the cultivation area, as well as those from the wetland area is carried out by binding it into the soil, because of the microbial activity of the root area, and via utilisation of the nutrients and evaporation of the water on the basis of plant activities. Drying waters of peat production areas are led by pumping it on the willow field and the wetland area through a perforated hose, from where the purified water is drifted through the field and a measuring well into the underneath watercourses (Figure 3).

In the spring 2012, the bottom of the willow field of the Raatteikonsuo mire was formed suitable for willow cultivation. After this the willow plantation was fertilised with bio- and ash granules. Water pumping system and a measuring well, through which the purified water is led into the underneath watercourses, were also constructed on the area. The willow cuttings, which represented predominantly the *Salix schwerinii* clone species, were planted by hand in the beginning of June. Due to the rainy summer, the cuttings started to grow well, and they grew in the summer just as the plantation at the Savonneva mire, established at Kyyjärvi in 2011.

The qualities of the drying waters of the peat production area and the water, leaving the willow cultivation area, were analysed in the summer 2012. Water was not pumped on the plantation area or the wetland area in the summer 2012, so it was not possible to estimate the purifying effect of the plantation area on the drying waters. The willow growth was not sufficiently developed and rooted, so that it would have been possible to purify the waters. Surveillance of the quality of the run-off waters has been started in the summer 2013.

Figure 3. Pumping of run-off waters to the willow plantation at Raatteikonsuo in the summer 2013.

5 AFTER-PURIFICATION OF THE PROCESS WATERS OF A WATER POROCESSING WASTE WATER PROCESSING PLANT WITH A WILLOW PLANTATION

In Sweden, there are 30 willow plantations by the side of waste water processing plants. The nitrogen rich purified process water is led on the willow cultivation field, where the objective is to reduce the nitrogen content of processed water before leading it into the waterways running into the Baltic Sea. This kind of new water processing system is in use in Enköping in the Middle Sweden. The process water of the waste water processing plant, led on the willow plantations, contains 800 mg of nitrogen per litre of water. This is 25% of the total nitrogen content of the process water coming into the waste water processing plant. In Enköping, the process water is pumped into storage basins, from which it is led via sluicing pipes on the plantations during the growing season (from May to September). The size of the plantation in Enköping is 75 ha. The objective is to increase, by using the plantation, the capacity of the waste water processing plant. It is possible to remove annually about 11 000 kg of nitrogen and 200 kg of phosphorus from the process waters. The amount of the water led on the willow field is 200 000 m^3/a, of which the share of process waters of waste water processing plant is 20 000 m^3. By using the willow field, it is possible to remove 68% of the nitrogen from the process water. Nitrogen removal in Enköping amount for 147 kg and phosphorus removal 2.7 kg/ha of willow field annually. The annual biomass growth of the willow corresponds to 6 – 12 tons/hectare (Dimitriou, I. & Aronsson, P. 2000).

Based on the Swedish example, the Outokumpu waste water processing plant was equipped with a willow plantation in June 2012 (Figure 4). The objective of this experiment was to investigate the utilisation of the willow stand in waste water purification. The area of the plantation was 0.3 ha and the willow species used at the area was *Salix schwerinii*. The cuttings were planted, just like at the Savonneva mire, into paired rows, the planting density being 16 000 cuttings per hectare. Purified water is led from the waste water processing plant to after-purification on the willow field through a manifold of 0.8 m diameter. The manifold is equipped with 40 mm side arms, led through the whole plantation. Wholes have been cut to the side arms at the distance of 2 metres from each other, which ensure the even distribution of water on the whole area. Before the planting the cutting, the rows were equipped with plastic foil, the objective of which is to render the growth of weeds.

About 97 m^3 of purified waste water from waste water processing plant was led on the willow plantation in the summer 2012. According to the analyses, carried out by the Finnish Environment Institute (SYKE), the willow plantation binds significant amounts of nitrogen. In the beginning of the plantation, the nitrogen compounds are bound in the field, because biomass amount of the willow plantations in 2012 was small. In 2013, the continuous research will give a realistic figure on effect of willow plantations in reduction of nitrogen emissions from after-treatment of waste water processing plant. The plantation started to grow well in 2012.

Figure 4. Willow plantation at Outokumpu waste water processing plant in the summer of 2012.

6 HARVESTING AND DELIVERY OF WILLOW TO THE PLANT

Harvesting tests for willow were carried out in Liperi in the summer 2012. Drying of willow stems - harvested as whole-trees - in storage piles, crushing of stems, and the delivery of the crushed biomass for combustion tests at the Joensuu power plant in the spring 2013, was also investigated. A literature survey was carried out before harvesting test on harvesters and harvesting methods.

The literature survey studied especially the equipment, used for harvesting of willow in foreign countries. The methods can be divided coarsely into four main methods: harvesting as chips, whole-trees, bales and harvesting using felling head equipped farming tractor. All these methods have their own advantages and disadvantages. Harvesting with special equipment is efficient and the harvesting costs of them are low. Harvester- or tractor-based harvesting is the most commonly used harvesting chain in the few small willow plantations in Finland (Figure 5). This method is used, because it is unprofitable to invest in special equipment at small plantations, so the existing machinery is used instead.

The practical research concentrated in investigation of whole-tree harvesting chain, used in harvesting of energy wood. A farming tractor, equipped with a guillotine clamp, was used as the harvesting machine. The willow stems were transported at the roadside in a tractor-pulled trailer. Harvesting tests were mainly carried out with 5 – 6 years old domestic willows. The profitability of a two-staged harvesting chain, in which the felling and the short distance haul were carried out separately, appeared to be best. Harvesting costs of willow stems as whole-trees at the roadside were at the lowest 13.7 €/MWh, and 18.2 €/MWh at the plant as wood chips. Harvesting costs of willow chips can be halved with special harvesting equipment, used especially in Sweden. Hence the willow chips would be competitive fuel with forest chips.

The research included two willow storage piles, the first one was made of 5 – 6 year old Siberian willow (*Salix schwerinii*) and the other one of 5 years old black willow (*Salix myrsinifolia*). Both storage stockpiles were dried during the storage, which continued until the winter 2013. The Siberian willow storage, located at an open and windy area, dried best.

Willow storages in Siikasalmi ware crushed during the storage tests, and the crushed willow biomass was delivered to the Joensuu thermal power plant, owned by

Fortum, where VTT carried out combustion tests using this willow fuel. In total 488 bulk m^3 of crushed willow was delivered from Siikasalmi, Liperi. Crushing and the delivery to the plant succeeded well. The fuel, however, contained some long branches, which caused problems in the feeding of the crushed willow into the boiler.

Figure 5. Harvesting of willow in Liperi in spring 2012.

7 COMBUSTION OF WILLOW CHIPS

The combustion task consisted of three subtasks: literature review, pilot-scale combustion tests and a full-scale combustion demonstration in a 30 MW_{th} district heating plant.

The literature review on willow combustion was carried out in order to obtain the typical fuel properties of willow, to learn from previous experiences on willow and to find the most relevant aspects to study in this project. According to (mainly) Swedish experiences (Hjalmarsson, A.-K et al. 1998), willow seemed to be more challenging fuel than traditional Nordic woody biomasses. In bubbling fluidised bed boilers (BFB), bed agglomeration had occurred when willow was used as the only fuel. In some plants, fouling and corrosion of the superheater tubes were observed due to too high share of willow in the fuel mix. Some laboratory and pilot scale studies also confirmed the occurrence of corrosive chlorine in superheater deposits (Skrifvars, B.-J. et al. 1997, Ala Khodier, H. M. 2011) and higher bed agglomeration tendency of willow compared to traditional woody biomasses (Grimm, A., et al. 2011, van der Drift, A. et al. 1999).

The purpose of the pilot-scale combustion experiments was to characterise the combustion properties of the most promising willow species in Finland, *Salix schwerinii*, in fluidised bed combustion conditions using 15 kW electrically stabilised BFB reactor at the VTT Technical Research Centre of Finland. The reactor offers various measurement possibilities and provides realistic temperature profiles and residence times and thus, the results can be scaled to full-scale plants with good accuracy. The reactor has been presented earlier in more detail e.g. in (Aho, M. et al. 2008, Aho, M., Vainikka, P. et al. 2008). From the experiments, it was found that the studied willow was comparable to good quality whole tree chips: fouling propensity was low, no chlorine was found in the deposits and bed agglomeration was not a problem. This was mostly due to very low chlorine content (0.003 wt.% d.b.) and moderate alkali content (K 1 700 mg/kg d.b.) in the fuel (Table 1).

Table 1. Some fuel analysis results from the willow sample used in pilot experiments.

Analysis	Result	Value	Method
Ash content 550 °C	1.5	wt.% dry	EN 14775, EN 15403
NCV, net calorific value	18.58	MJ/kg dry	EN 14918, EN 15400, ISO 1928
C H N	49.9 6.1 <0.3	wt.% dry	EN 15104, EN 15407, ISO 29541
S	0.03	wt.% dry	ASTM D 4239 (mod.), EN 15289
Cl	0.003	wt.% dry	SFS-EN ISO 10304-1:2009 (mod.)
K	1700	mg/kg dry	EN 15290:2011 A (mod.) SFS-EN ISO 11885:2009 (mod.)

The full-scale willow combustion tests were carried out at Fortum's 30 MW_{th} heating plant located in Joensuu, Finland (Figure 6). Typically a 50:50 mixture of forest chips and by-products of wood industry (sawdust, bark etc.) are used in the BFB boiler of the plant. In these tests forest chips were replaced with hogged willow and the share of willow was increased gradually to 100. A total of about 500 loosem^3 of willow was combusted during the two day test campaign.

The main focus of the tests were 1) to obtain practical experience on willow combustion as willow had not been used in Finland in this scale before 2) to study handling and feeding properties and 3) to study the effects of willow on fly ash quality.

As willow was crushed instead of chipping, the resulting particles were long, narrow and "splintery". Thus, willow had a tendency to arch in the feeding silo and the arch had to be broken couple of times. If willow would have been chipped even these small problems could have been avoided. Some indication of limitations to achieve full load during 100 % willow combustion was noticed by the plant operators. Otherwise, no negative effects on boiler usability could be observed. In this aspect, willow is a lot more attractive fuel than for example reed canary grass (RCG) that has been previously utilized as a short rotation energy crop in Finland.

The study on the effect of a willow on a fly ash composition is still in progress. The main interest is to find out if the higher heavy metal content in willow affects the utilization of fly ashes as forest fertilizers.

As a summary, at least the willow studied in this project seems to be quite attractive fuel combustion wise. Previous experiences might have given willow worse reputation than it deserves. In future it is still necessary to study in more detail the effect of soil and fertilizers on the composition of the willow before final conclusions can be made.

Figure 6. Unloading of willow chips from the truck trailer at Fortum's power plant.

8 CONCLUSIONS

Cut-over bogs, fields poorly suitable for other cultivation, and the fields removed from agricultural use form the major potential areas for cultivation of willow in Finland. At the areas of Northern Karelia and Central Finland, which participated in this research, the amount of potential willow cultivation area is several thousands of hectares.

A lot of new information has been collected in the project of the cultivation of willows for different purposes. According to the research willow chips are very suitable for the use as fuel. The utilisation of willow stands for purification of the run-off waters of peat production areas seems also to be a promising alternative. By using the willow plantations, it is also possible to reduce the nitrogen emissions of the process waters from waste water purification plants. It is possible to use ash and bio-based fertilisers for fertilising the willow plantations. Establishment of a willow plantation and the harvesting of willows still require further development.

The final business opportunities and potential for willow growing in Central Finland and North Karelia will be made at the end of the project based on the results of the project.

8 REFERENCES

Aho, M., Gil, A., Taipale, R., Vainikka, P. & Vesala, H. (2008) . A pilot scale fireside deposit study of co-firing Cynara with two coals in a fluidised bed. Fuel 87 (2008) 58–69.

Aho, M., Vainikka, P., Taipale, R. & Yrjas, P. (2008). Effective new chemicals to prevent Cl-originated superheater corrosion in power plants. Fuel 87 (2008) 647–654.

Ala Khodier, H. M. (2011). Co-firing fossil fuels and biomass: combustion, deposition and modelling, PhD Thesis, School of Applied Sciences, Cranfield University, UK, 2011, 303 p.+Appendices

Dimitriou, I & Aronsson, P. 2000. Swedish experiences from wastewater irrigation on large-scale Short-Rotation. Swedish University of Agricultural Sciences, Ullsväg 16, Box 7043, 75007, Uppsala, Sweden.

Grimm, A., Skoglund, N., Boström, D. & Öhman, M. (2011). Bed Agglomeration Characteristics in Fluidized Quartz Bed Combustion of Phosphorus-Rich Biomass Fuels, Energy Fuels, 2011, 25 (3), pp. 937–947.

Hjalmarsson, A.-K. & Ingman, R. (1998). Erfarenheter från förbränning av salix (Experiences from combustion of willow), Värmeforsk Report No 631, Värmeforsk Service AB, Stockholm, Sweden, 1998, 31 p. (In Swedish).

Leinonen, A., Sihvonen, J., Kaipiainen, E., Villa, A., Korpijärvi, K. & Reinikainen O. 2012. Establishment of willow plantation on peatland of Raatteikonsuo (Pajuviljelmän perustaminen Raatteikonsuolle). Sustainable energy willow production and use – project. Research report VTT-R-08435-12. 46 p. + app. 16. In Finnish.

Paappanen, T., Leinonen, A. Villa, A. Kaipiainen E., Reinikainen, O. 2012. Establishment of willow plantation on cut-over peatland of Savonneva (Pajuviljelmän perustaminen Savonnevan turvetuotantoalueelle). Sustainable energy willow production and use – project. Research report VTT-R-00651-12. 42 p. + app. 4 p. In Finnish.

Sihvonen, J. Leinonen, A. Villa, A. 2013. Harvesting, storing and supply to power plant of willow (Pajun korjuu, varastointi ja toimitus laitokselle). Sustainable energy willow production and use – project. Research report VTT-R-00761-13. 75 p. + app. 6 p. In Finnish.

Skrifvars, B.-J., Sfiris, G., Backman, R., Widegren-Dafgård, K. & Hupa, M. (1997). Ash Behavior in a CFB Boiler during Combustion of Salix, Energy Fuels 1997, 11, pp. 843–848.

van der Drift, A. & Olsen, A. (1999). Conversion of biomass, prediction and solution methods for ash agglomeration and related problems, Final Report, ECN-C-99-090, ECN, 1999, 62 p.+Appendices

TROPICAL BIOMASS WASTE MANAGEMENT POTENTIALS: THERMAL INVESTIGATION OF NIGERIAN WOODWASTES FOR ENERGY PRODUCTION

Kehinde Oluoti[1] and Tobias Richards[2]
[1, 2]School of Engineering, University of boras, Sweden

Resource recovery through efficient waste management is today becoming more and more important. However, many countries around the world, and among those the majority of tropical countries, have not yet adopted this. The heaps and stretch of refuse which adorn e.g. Nigerian roads, pollute the environment and disfigure the landscape are direct results of inefficient waste management. It is estimated that about 30,064,320 m^3 of wood wastes is being generated annually from different sawmills and other wood industries in Nigeria (Babayemi *et al.* 2010). This paper seeks to examine the viability of such wood wastes for the purpose of energy recovery instead of being burnt or allowed to rot away.

Two tropical biomass species: *Guarea thompsonii (Obobo)* and Tectona *grandis (Teak)* as representatives of Nigerian sawmill wastes were considered for thermal investigation and their reaction kinetics were determined using data from a Thermogravimetric Analyzer (TGA). The samples were subjected to non-isothermal pyrolysis at temperatures up to 900°C with heating ramps 2°C/min, 5°C/min, 8°C/min, 12°C/min, 15°C/min and 20°C/min. The resulting solid char obtained was subjected to isothermal gasification with CO_2 as gasifying agent at 1000°C. From these data an Arrhenius expression was determined. More specifically, the Activation energy Ea, and the Pre-exponential factor A were determined for the pyrolysis stage and the reaction rate constant K was determined for the gasification stage.

The determination of proper kinetic parameters is very important in framing a proper design of the reactor which is fundamental to achieving an optimal conversion of the chemical energy present in the biomass feedstock. Four iso-conversional methods (Flynn, Wall and Ozawa (FWO); ***Kissinger-Akahira-Sunose*** (KAS); Friedman and Li-Tang), one peak height method (Kissinger) and two model-fitting methods (Coats-Redfern and Kennedy-clerk) were employed to determine the kinetics parameters (Ea and A), while the gasification kinetic rate constant K values were determined using two gas-solid reaction models: volumetric reaction model (VRM) and shrinking core model (SCM). It was found that the calculated activation energy (E_a) and Pre-exponential factor (A) using the above iso-conversional methods were in the range of 130-155 kJ/mol and 4.14 $x10^{11}$ to 1.24 $x10^{17}$ min^{-1} respectively for *Obobo* and 140-175kJ/mol and 6.59 x 10^{13} to 3.32 $x10^{23}$ min^{-1} respectively for *Teak*. The overall results showed good agreement with values derived for non tropical wood samples using an example of poplar wood (*populus L.)* as investigated by Katarzyna *et al.* (2011).

Contact information:

[1]*Kehinde Oluoti, School of Engineering, University of Boras, SE-501 90, Boras, Sweden. Tel.: +46-334354585. E-mail:* kehinde.oluoti@hb.se. **[2]**Tobias Richards, Professor *(Corresponding author), School of Engineering, University of Boras, SE-501 90, Boras, Sweden. Tel.: +46-334354207. E-mail:* tobias.richards@hb.se

Appendix

References

Babayemi, J.O. and K.T. Dauda, *Evaluation of Solid Waste Generation, Categories and Disposal Options in Developing Countries: A Case Study of Nigeria.* Journal of Applied Sciences and Environmental Management, 2010. 13(3).

K. Slopiecka, P. Bartocci, F. Fantozzi,*Thermogravimetric analysis and Kinetic study of poplar wood pyrolysis.* Third International Conference on Applied Energy - 16-18 May 2011 - Perugia, Italy, pages 1687-1698.

With poor management of wood wastes as shown above, the problems posed by these wastes are many and are as listed below:

(1) They degrade the urban environment,
(2) Reduce its aesthetic value, produce offensive odors during the rains and pollute the air with smoke when wastes are burnt uncontrollably.
(3) They also constitute health hazards in themselves if they are not timely disposed and thus become breeding places for worms and insects.

The sawdust often spilled into the lagoons, waterways, etc, sometimes blocking the drainages and canals draining into the lagoon.
In conclusion, working on the thermal investigation of these resources (from the tropics) to probe their suitability towards energy recovery is highly desirable.

SPATIALLY EXPLICIT METHOD FOR ESTIMATING BIOMASS POTENTIALS FROM FINAL FELLINGS – CASE CENTRAL FINLAND

Eero Muinonen 1, Finnish Forest Research Institute,
Joensuu Unit, PO Box 68, FI-80101 Joensuu, Finland eero.muinonen@metla.fi
Perttu Anttila 1, perttu.anttila@metla.fi,
Jaakko Heinonen 1, jaakko.heinonen@metla.fi & Jukka Mustonen 2, jukka.mustonen@storaenso.com

1 Finnish Forest Research Institute, Joensuu Unit, PO Box 68, FI-80101 Joensuu, Finland
2 Stora Enso, Talvikkitie 40 C, FI-01300 Vantaa, Finland

ABSTRACT

This study focuses on the technical potential of primary forestry residues, i.e. logging residues and stumps, from final fellings. Following a spatially explicit approach, general framework of a calculation model for the potential is presented. Satellite remote sensing based image segmentation method, map data and multi-source forest inventory data were integrated for acquiring forest stand level attributes on forestry land. The nature conservation areas and areas of the Natura 2000 network were excluded from the analyses. Technical and environmental aspects, such as steepness of slope and soil fertility, were taken into account using constraints.

Potential of logging residues and stumps depend on harvesting of industrial roundwood. Statistics for the harvesting levels of industrial roundwood from final fellings at municipality formed the basis for the different scenarios. Three harvesting level scenarios for each of the 23 municipalities under analysis were made: the average (Avg) scenario, the minimum (Min) and maximum (Max) scenarios. Optional constraints in this study included forwarding distance and requiring spruce as the main tree species in stump harvesting sites. This presentation gives an example case of an implementation of constraints from the different aspects to the approach.

We present summary results in the Forestry Centre of Central Finland in the harvesting scenarios and the effects of the optional constraints. After all constraints were included, the technical potentials for logging residues and stumps decreased 64 % and 85 %, respectively, compared to the theoretical potentials at Forest Centre level. Comparison is made with other results available for the region. Main requirements for the model application are reliable forest inventory methodology combined with statistical biomass models. This approach proved to be very applicable for accounting for the various spatial constraints to the calculation model of biomass potential.

LOGFORCE™ FOR FOREST INDUSTRY TRANSPORTATION COMPANIES TO IMPROVE BIOMATERIAL SUPPLY CHAIN

Kari Peltonen, Fifth Element Oy, Niittykatu 8, FIN-02200 ESPOO, Kari.Peltonen@FifthElement.fi

Markku Virtanen, Fifth Element Oy, Väinönkatu 26 B, FIN-40100 JYVÄSKYLÄ
Markku.Virtanen@FifthElement.fi

ABSTRACT: Fifth Element is a Finnish software company that makes change happens. We create solutions for interfacing with company stakeholders, bringing new ways of working for employees, partners and customers. Our customers are the industry's leading companies in Finland and its nearby areas. Fifth Element's activities are based on in-depth knowledge of new multichannel web technologies and location information, as well as full dedication to customer project.

For supplier it is important to secure total deliveries to customer, for example to pulp mill, sawmill or power station. Usually total responsibility belongs to suppliers but entrepreneurs have very important role in logistic chain. They are in charge of transportation in certain geographical area.

LogForce™ is Fifth Element's service-based solution to forest and bioenergy industry. LogForce™ features multiple functionalities to efficient supply chain management and field work through the means of a full-scale enterprise resource planning. This will cover wood material deliveries from forest to mill side including round wood and biomass as well as co-products. LogForce™ can be easily integrated into subscriber´s ERP systems to comply with other industry needs.

The aim of the service is to support transport companies in achieving a high utility rate of equipment. This is achieved by having up-to-date information from the field and connections to customer organizations' systems. Concentrating on delivery amount management and efficient stock cycle are benefits from the point of view of forest companies ordering transport services. Cost-effectiveness of software development will also be improved.

The software service covers the office and vehicle software needed by transport companies.
Usability in particular has been taken into consideration in developing the service. To ensure this, the
Service has been implemented in close co-operation with transport companies and their customers. Metsä Group and Stora Enso are the first commissioners of the service.

Keywords: supply chain, location information, task management, resource management

A FIELD INVESTIGATION INTO PHYSICAL WOOD PROPERTIES OF FIRST THINNINGS THAT INFLUENCE ENERGY CONVERSION

Nicholas Mockler, Tom Kent and Eleanor Owens
Waterford Institute of Technology
Cork Road, Waterford City, Ireland
n.mockler@hotmail.com; tkent@wit.ie

In order to compete with fossil fuels and for the successful development of economically viable wood fuel supply chains in Ireland, there is a need to address the ramifications of non – adherence to wood fuel quality. As a result, this has instigated research into developing wood fuel property databases of forest biomass fuel sources that have an influence on the combustion efficiency of wood. The fuel properties investigated were the moisture content and basic density of above ground biomass partitions, with emphasis on spatiotemporal variation. The quantities of total above ground biomass were also estimated. Six species of first thinning age classes (12 – 17 years) were investigated: alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), birch (*Betula Spp.*), lodgepole pine (*Pinus contorta*), Norway spruce (*Picea abies*) and Sitka spruce (*Picea sitchensis*).

With the exception of ash, this study found no distinguishable seasonality in the moisture content of stem wood sections. Branch wood demonstrated greater seasonality with moisture content for all the six species, experiencing a reduction at spring time in comparison to winter. Basic density decreased with an increase in latitude for all the six species. For all the six species it was conclusively found that if whole trees are harvested from first thinnings, this can lead to a twofold increase in the biomass that can potentially be harvested for energy, as opposed to harvesting roundwood only for energy.

KEYWORDS: Fuel, Quality, Wood Biomass.

1 INTRODUCTION

In Ireland, an increase in the consumption of wood for energy has been instigated in recent years due to a number of concerns. These concerns include a heavy dependence on finite resources of imported fossil fuels, declining indigenous energy production and the adverse effects of climate change. As a result of a number of policy measures and incentives [11, 12, 17, 41], the use of wood for energy has been ratified in making a contribution to resolving issues associated with increasing energy independence and mitigating climate change in Ireland. After wind energy, wood energy is the second largest contributor to renewable energy generation [10]. Wood energy consumption represents 0.81% of total primary energy requirement at present, whereby 33% of the total annual roundwood harvest has been used for wood energy consumption [28, 29]. However, if the reliance on cut – to – length harvesting systems for the production of roundwood is maintained, there will not be enough wood biomass in Ireland to supply future demands for energy [9, 46]. As a result, the harvesting of whole trees from first thinnings, in addition to above and below ground logging residues from clearfell areas has been identified as a potential option to fulfil demand shortfalls forecasted for wood energy consumption in Ireland [26, 27]. Despite the potential contributions of residual woody biomass material to demands for wood energy, this has instigated a need to research the operational supply chains for the harvesting of this material to justify its economic viability for Irish conditions. The research and development of these new supply chains include a need to compile wood fuel property databases of forest biomass fuel sources and the resultant wood fuel products, as quality control is a vital prerequisite in ensuring the successful combustion of wood. As another paper being presented at this conference concerns the procurement of above ground logging residues from clearfell areas [7], this paper will focus upon the characterisation of the above ground biomass procured from first thinnings.

1.2 First thinnings as a wood energy resource in Ireland

First thinnings are a widespread age class of woody biomass material available for harvesting in Ireland. First thinnings represent two thirds of the forestry estate overall [37]. The majority of first thinning stands are privately owned. This is the direct result of a number of Government incentives allocated to private landowners to afforest land over the last 30 years. Due to its prominence, first thinning material has been targeted as a key source of wood fuel, and research has thus focused on the harvesting supply chains of this material through the Forest Energy Research Programme [27, 30]. Amongst these research efforts, wood fuel quality and trade standardisation has received particular scrutiny.

2 Standardisation and quality control of wood energy products

In wood energy terms, quality is defined by the influence of fuel properties on optimum energy output [1, 25, 33, 44]. Over the last decade the European Commission (EC) mandated the development of standards for the harmonisation of wood fuel trade within and outside the EU [1, 31, 51]. Standards are a set of rules to ensure quality which are described in unambiguous documents designed for repeatable and reproducible use [33, 51]. With this mandate for trade standardisation, the solid biofuels Technical Committee (TC) 335 was formed to develop standards in biomass trade [31]. Ireland is represented on TC 335 through the National Standards Authority of Ireland (NSAI) [32]. Other developments included the BioNorm project which evaluated the scientific testing procedures for both physical and chemical properties of wood, its suitability for energy conversion technologies, and the optimum utilisation of machinery operating in the field for the production of wood fuel [1, 3, 45].

In Ireland, independent audits of internal trade agreements between wood fuel producers and consumers has been initiated in recent years through the Wood Fuel Quality Assurance scheme (WFQA), instigated by preliminary testing of European Standards on the Forest Energy Research Programme [25]. The WFQA is an industry – led initiative to certify wood fuels produced in Ireland in accordance with the National Working Agreement 4: 2009: Woodfuel Quality Assurance – Requirements [42]. The resulting WFQA label is a quality mark awarded to wood fuel producers who meet the standards of external audits [31].

Standards also exist for sampling and scientific examination of physical and chemical wood fuel properties that influence optimum energy output. For practical purposes, the quantity of fuel, its origin, moisture and ash content are the most important parameters to specify when trading wood fuel, in addition to having an influence upon the economic viability of wood fuel supply chain operations [31, 43, 44]. Other properties are typically informative (voluntarily specified) when trading wood fuel such as density, heating values, presence of volatile matter and chemical properties.

3 Aims and objectives

Characterisation of wood fuel properties assists in the optimisation of operations concerned with the harvesting, processing, seasoning and conversion of wood into energy. In Ireland, there are no wood fuel property databases of forest biomass fuel sources. This study sought to address this knowledge deficiency through the physical characterisation of the above ground biomass partitions derived from first thinnings (12 – 17 years of age). This study involved six tree species of commercial merit in Ireland: alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), birch (*Betula spp.*), lodgepole pine (*Pinus contorta*), Norway spruce (*Picea abies*) and Sitka spruce (*Picea sitchensis*). These species represent 76% of forest cover in Ireland [37].

To achieve this aim the following objectives were met:

1. To characterise moisture content of different above ground biomass partitions (stem sections and branches), the most important quality parameter of wood fuel as it can have an adverse influence on combustion efficiency, storage properties and transportation.

2. To characterise basic density, an important fuel quality parameter that describes how much wood is contained per unit volume for energy consumption.

3. To quantify total above ground biomass and develop parameters that can convert volume estimates from inventory data to biomass and energy content.

4. To create a repository of the material used in this study for chemical analysis.

The primary variation sources investigated in this study were the spatiotemporal differences of moisture content *in situ*. This was to identify the optimum period for harvesting and seasoning wood for energy in Ireland. This study also allowed for an opportunity to investigate the stem wood basic density of the six species in this study. Basic density data exists only for Sitka spruce in Ireland, at least within the public domain [15, 18, 20, 38, 52, 53, 54]. The sampling methodologies in this study allowed for the quantification of above ground biomass. This was to facilitate the conversion of volume inventories to biomass and energy content where the interest is to quantify first thinnings on this basis, especially where the harvesting of whole trees is concerned. This is because volume inventories traditionally only account for stem sections to a specified top diameter and do not account for residue material (e.g. stem sections < 7 cm diameter and branches).

4 METHODOLOGY

To investigate the spatiotemporal aspect of proceedings, sites ready for a first thinning of the six tree species in this study were sought within three different latitudinal zones in Ireland: the South East (52^{o}N), Midlands (53^{o}N) and North West (54^{o}N). The first field study was undertaken in the South East region during August 2011. Thereafter, each region was visited during January (winter), May (spring) and July (summer) 2012. Sample trees within the diameter size class distribution of the quadratic mean DBH were felled and extracted to a landing. After the felling and extraction of sample trees, biomass components were partitioned and weighed. These partitions included merchantable stem sections, stem sections < 7 cm diameter, live branch wood and dead branch wood. Discs of approximately 25 – 30 mm were sampled from every metre on stem sections to 80% of relative height. In addition, five live branches and one dead branch per tree were sampled. Stem disc and branch subsamples were used to determine moisture content in accordance with European Standard specifications [6]. Before oven drying stem discs for the determination of moisture content, these were first estimated for volume in order to determine basic density, concurrent with the appropriate classification of samples oven dried to 105^{o}C as a proportion of sample fresh volume [36]. Dry Weight:Wet Weight ratios were estimated from disc and branch subsamples for the conversion of total partition fresh weights measured in the field, to total partition oven dry weights [34].

The oven dry partition data was used to construct Biomass Expansion Factors (BEFs) as a function of the merchantable stem biomass for the six species. The basic density data and BEFs were multiplied into the volume/ha ascertained from inventory data to calculate biomass in oven dry tonnes (odt) per/ha. In tandem, GJ/ha was calculated by multiplying standard reference values for the energy content of virgin woody biomass into the odt/ha. The total sample size was 270 trees, 45 per species, 15 trees per region and five trees per site visit. The total subsample size was 4934 divided between stem discs, branch wood and foliage.

5 RESULTS AND DISCUSSION

5.1 Moisture content

Tables I and II in this section illustrate the spatiotemporal differences in the moisture content of stem wood and branch wood for each species within each location. Identical letters signify that no statistically significant differences ($p > 0.05$) occurred within rows. Different letters signify that statistically significant differences occurred within rows ($p < 0.05$).

Table I. *Spatiotemporal moisture content variation in stem wood.*

Spatiotemporal Stem Wood Moisture Contents (%)

South East	**Dormancy**	**Flushing**	**Growing Season**
Alder	48.1 a	50.7 b	49.1 ab
Ash	35.1 a	36.8 b	38.9 c
Birch	45.4 a	47.4 b	46.3 ab
Lodgepole pine	62.3 a	59.5 b	59.9 b
Norway spruce	64.2 a	61.9 b	62.9 ab
Sitka spruce	59.6 a	58.6 a	60.0 a
Midlands	**Dormancy**	**Flushing**	**Growing Season**
Alder	50.3 a	51.5 a	54.0 b
Ash	33.7 a	36.7 b	41.0 c
Birch	45.3 a	43.9 a	47.2 b
Lodgepole pine	57.5 a	59.0 ab	60.4 b
Norway spruce	64.2 a	61.9 b	64.0 a
Sitka spruce	59.9 a	57.4 b	60.8 a
North West	**Dormancy**	**Flushing**	**Growing Season**
Alder	54.4 ab	55.1 a	53.8 b
Ash	35.8 a	39.5 b	42.3 c
Birch	47.3 a	45.3 b	46.0 b
Lodgepole pine	59.2 a	60.4 a	63.2 b
Norway spruce	65.9 a	67.3 b	68.1 b
Sitka spruce	63.9 a	64.0 a	65.5 a

Table II. *Spatiotemporal moisture content variation in branch wood.*

Spatiotemporal Branch Wood Moisture Contents (%)			
South East	**Dormancy**	**Flushing**	**Growing Season**
Alder	50.5 a	50.8 a	44.0 b
Ash	38.9 a	49.5 b	47.0 b
Birch	46.0 a	50.8 b	33.4 c
Lodgepole pine	54.7 a	56.8 a	47.3 b
Norway spruce	49.0 a	42.9 b	45.9 c
Sitka spruce	50.6 a	47.1 ab	46.1 b
Midlands	**Dormancy**	**Flushing**	**Growing Season**
Alder	52.1 a	37.4 b	57.0 c
Ash	41.2 a	39.6 a	52.2 b
Birch	46.4 a	34.4 b	52.1 c
Lodgepole pine	55.1 a	48.0 b	54.5 a
Norway spruce	51.4 a	41.7 b	50.0 a
Sitka spruce	49.0 a	40.7 b	46.9 a
North West	**Dormancy**	**Flushing**	**Growing Season**
Alder	54.5 a	41.3 b	43.9 c
Ash	45.3 a	44.3 a	42.6 a
Birch	52.0 a	37.1 b	39.1 b
Lodgepole pine	57.6 a	52.0 b	56.3 a
Norway spruce	59.5 a	47.9 b	52.8 c
Sitka spruce	61.5 a	42.5 b	46.5 c

With stem wood, the only species of the six to show distinguishable spatiotemporal variation in moisture content was ash. Ash stem wood moisture content was significantly lower in winter in comparison to spring and summer within each location sampling took place. This may be postulated to be due to ash' vascular orientation as a ring porous hardwood tree species, having larger vessels over the course of the growing season, which decline in size during dormancy due to a higher ratio of latewood in contrast to earlywood allocated to annual growth rings [4,8]. The other five species did not show distinguishable temporal differences in stem wood moisture content, ranging no more than 2 – 4% maxima over the course of seasons.

With branch wood, the most distinguishable trend was the reduction of moisture content at spring time in comparison to winter, bar three exceptions. This is postulated to be due to increased temperatures, high vapour pressure deficits, and lower relative humidity of air coinciding with new tree growth during spring time leading to an increase of demand for water in foliar regions [23]. Moisture content decreased or increased again in branch wood over the course of summer. Bar two exceptions, where moisture content increased over the summer period, it did not exceed the values recorded during the dormant season. The rise again in moisture content during the summer may be postulated to be due to the maturation of foliage, in addition to the cessation of shoot elongation and apical meristem growth, thus leading to less of a demand for water in foliar regions during the latter period of the growing season [4].

The aim of this work was to define optimum harvesting and seasoning periods for wood fuel under Irish conditions. This basic research has confirmed that the best period for harvesting and seasoning wood fuel is between the period of March – August, whereas September – February is not suitable. This is primarily due to the ambient drying conditions for seasoning wood. During March – August, the climate of Ireland experiences lower rainfall, higher temperatures and lower relative humidity of air, thus facilitating more favourable conditions for seasoning wood [26]. On the otherhand, the period of September – February encounters opposite climatic conditions to the period during March – August. The recommendations from this basic research also complies with applied research data into the harvesting and seasoning of wood for fuel in temperate forest biomes that experience the four seasons including Ireland [7, 13, 16, 27, 30, 39, 49, 50, 51].

5.2 Basic density

Table III in this section illustrate the spatial differences in basic density of the six tree species. Identical letters indicate that no statistically significant differences occurred within rows ($p > 0.05$). Different letters indicate that statistically significant differences occurred within rows ($p < 0.05$).

Table III. Spatial variation of basic density.

Spatial Basic Densities (kg/m^3)			
Species	**South East (kg/m^3)**	**Midlands (kg/m^3)**	**North West (kg/m^3)**
Alder	412.3 a	407.4 a	351.5 b
Ash	543.3 a	480.1 b	463.9 b
Birch	512.9 a	484.5 b	461.3 c
Lodgepole pine	384.0 a	377.5 ab	367.5 b
Norway spruce	363.3 a	348.2 b	322.1 c
Sitka spruce	381.6 a	374.9 a	351.0 b

The most distinguishable trend from a spatial perspective was the reduction of basic density with an increase in latitude for the six species in this study. This was most pronounced in the North West region. The reduction in basic density is postulated to be due to an increase in rainfall with latitude, as others have found that this can lead to reduction in basic density due to an increase in radial growth resulting in more earlywood to latewood on annual growth rings [5, 14, 19, 21, 24, 36, 55]. Basic density has also been found to increase at more southerly latitudes due to increased accumulated temperatures [2, 47, 55]. This in effect gives rise to longer growing seasons and extended development of latewood. However, average accumulated temperatures in Ireland are equitable across the country as a whole [35], thus rainfall may be a better descriptor of the spatial trends as the North West region of Ireland experiences the most rainfall in the country [35]. As this study did not measure radial growth directly, in addition to the innumerable variation sources with basic density, more sophisticated analysis of radial growth and cognisance to site descriptors from a silvicultural perspective (genetics, spacing etc.) would be required. However this was beyond the scope of this study.

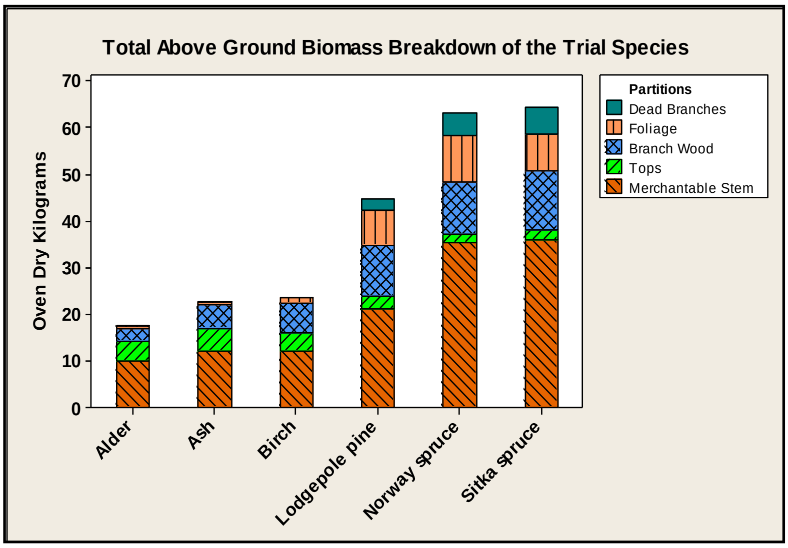


Figure I. Proportions of oven dry above ground biomass of the trial species.

5.3 Biomass proportions and the extrapolation of estimates.

This study found if whole trees from first thinnings are harvested for energy, this can lead to a twofold increase in the biomass that can be harvested, as opposed to harvesting merchantable stem sections for roundwood only. Due to higher growth rates, the coniferous species possessed two – three times more biomass than the broadleaf species; thus more energy on a per oven dry mass basis. This was also apparent when the biomass calculations were expanded on a per hectare basis as demonstrated in Table IV, which shows that the coniferous species possess 4 – 25 times the volume, mass and energy content when compared to the broadleaf tree species.

Table IV. *Conversion of volume/ha to biomass and GJ/ha.*

Alder	**Age**	**YC (m^3/ha/yr)**	**Vol/ha (m^3)**	**Basic Density (t/m^3)**	**BEF**	**Biomass odt/ha***	**GJ/ha**
South East	14	6	9	0.41	2.2	8.1	153.4
Midlands	16	6	9	0.41	1.9	7.0	132.5
North West	12	12	12	0.36	2.7	11.7	220.4
Ash	**Age**	**YC (m^3/ha/yr)**	**Vol/ha (m^3)**	**Basic Density (t/m^3)**	**BEF**	**Biomass odt/ha**	**GJ/ha**
South East	16	6	9	0.54	1.7	8.3	156.2
Midlands	16	6	9	0.48	1.9	8.2	155.1
North West	12	10	11	0.46	1.7	8.6	162.6
Birch	**Age**	**YC (m^3/ha/yr)**	**Vol/ha (m^3)**	**Basic Density (t/m^3)**	**BEF**	**Biomass odt/ha**	**GJ/ha**
South East	15	6	9	0.51	1.9	8.7	164.8
Midlands	16	6	9	0.49	2.4	10.6	200.0
North West	12	12	12	0.46	2.2	12.1	229.5
Lodgepole pine	**Age**	**YC (m^3/ha/yr)**	**Vol/ha (m^3)**	**Basic Density (t/m^3)**	**BEF**	**Biomass odt/ha**	**GJ/ha**
South East	13	14	40	0.38	2.2	33.4	634.6
Midlands	16	14	52	0.38	2.0	39.5	750.5
North West	16	10	76	0.37	2.6	73.1	1388.9
Norway spruce	**Age**	**YC (m^3/ha/yr)**	**Vol/ha (m^3)**	**Basic Density (t/m^3)**	**BEF**	**Biomass odt/ha**	**GJ/ha**
South East	17	18	158	0.36	1.6	91.0	1729.0
Midlands	16	16	94	0.35	2.1	69.1	1312.9
North West	16	20	185	0.32	1.8	106.6	2025.4
Sitka spruce	**Age**	**YC (m^3/ha/yr)**	**Vol/ha (m^3)**	**Basic Density (t/m^3)**	**BEF**	**Biomass odt/ha**	**GJ/ha**
South East	17	26	232	0.38	1.6	141.1	2680.9
Midlands	16	22	124	0.38	1.8	84.8	1611.2
North West	16	20	117	0.35	2.1	86.0	1634.0

***Oven dry tonnes per/ha**

6 Conclusion

This project is part of an initial phase to develop a fuel property database of forest biomass fuel sources conducive to Irish conditions. This work fulfilled its objectives for the physical characterisation of wood biomass material derived from first thinnings. This has also laid down the foundation for the development of a comprehensive database for the wood fuel properties of commercially available biomass, which can subsequently be supplemented with similar datasets for other species and biomass fuels. Future work will aim to characterise the ash contents and calorific values of the above ground biomass partitions from the material in this study. In tandem chemical analysis will also be carried out for this material.

Overall, the data accumulated from this study is restricted to an age class, particularly where the quantification of biomass is concerned through the use of basic densities and BEFs. Other future work will need to test the validity of these parameters in estimating the quantities of biomass available against the actual removals from first thinning operations. However, limiting the sampling to these species and age classes ensured the majority of potentially commercially available biomass for energy would be characterised, as larger size classes are already allocated for roundwood industrial wood production.

7 References

1. Alakangas, E., Valtanen, J., & Lavlin, J. (2006). CEN technical specifications for solid biofuels. *Biomass & Bioen. , 30*, 908-914.

2. Aosaar, J., Varik, M., Lohmus, K., & Uri, V. (2011). Stemwood density in young grey alder (*Alnus incana* (L.) Moench) and hybrid alder (*Alnus hybrida* A. Br.) stands growing on abandoned agricultural land. *Baltic For. , 17* (2), 256-261.

3. BIONORM. (2004). *BIONORM Project - Final Technical Report.* European Standards Committee.

4. Bowyer, J., Haygreen, J., & Shmulsky, R. (2007). *Forest Products and Wood Science: An Introduction* (5th ed.). Iowa: Iowa State Press University / AMES.

5. Bryan, J., & Pearson, F. (1955). The quality of Sitka spruce grown in Britain. *Emp. For. Rev.* , 144-149.

6. CEN. (2010). *EN: 14774 - 2 2010. Solid biofuels - Determination of moisture content - Oven dry method - Part 2: Total Moisture - Simplified Method.* Dublin: National Standards Authority of Ireland.

7. Coates, E., & Kent, T. (2013). Biomass estimates for mobilising wood for energy using compact residue logs on harvested conifer plantations in Ireland. *Proceedings of BIOENERGY 2013 – A Boost for Entire Industry*. Jyvaskyla: Finland.

8. Coder, K. (1999). *Tree ring porosity in hardwoods.* Athens: University of Georgia.

9. COFORD Round Wood Demand Group. (2011). *All Ireland roundwood demand forecast 2011 - 2028.* Dublin: COFORD.

10. Dennehy, E., Howley, M., O'Gallachóir, B., & Holland, M. (2012). *Renewable Energy in Ireland 2011*. Dublin: Sustainable Energy Authority of Ireland.

11. Department of Communications, Marine and Natural Resources. (2007b). *Bioenergy action plan for Ireland. Report to the ministerial task force on bioenergy.* Dublin.

12. Department of Communications, Marine and Natural Resources. (2007a). *Delivering a sustainable energy future for Ireland. The energy policy framework 2007 - 10.* Dublin.

13. Filbakk, T., Hoibo, O., & Nurmi, J. (2011). Modelling natural drying efficiency in covered and uncovered piles of whole broadleaf trees for energy use. *Biomass & Bioen. , 35*, 454-463.

14. Gardiner, B. (2011). Climate change, tree growth and timber properties. Newcastle: Forest Research.

15. Gardiner, J., & O'Sullivan, P. (1978). The effect of wide espacement on wood density in Sitka spruce (*Picea sitchesis* (Bong.) Carr.). *Irish For. , 35* (1), 45-51.

16. Gigler, J., van Loon, W., van den Berg, J., Sonnevald, C., & Meerdink, G. (2000). Natural wind drying of willow stems. *Biomass and Bioen.* , 153-163.

17. Government of Ireland. (2007). *National Climate Change Strategy 2007 - 2012.* Dublin: Department of the Environment, Heritage and Local Government.

18. Green, C., Tobin, B., O'Shea, M., Farrell, E., & Byrne, K. (2007). Above and belowground biomass measurements in an unthinned stand of Sitka spruce (*Picea sitchensis* (Bong) Carr.). *Eur. Jour. For. Res. , 126*, 179-188.

19. Henttonen, H. (1984). The dependence of annual ring indices on some climatic factors. *Acta Forestal. Fenn. , 186*.

20. Javadi, Z., MacSiúrtáin, M., & Gardiner, J. (1983). The effect of tree espacement upon wood density in Sitka spruce (*Picea sitchesis* (Bong.) Carr.). *Irish For. , 40* (2), 92-97.

21. Jeffers, J., & Dowden, H. (1964). Moisture content and specific gravity of freshly - felled conifers: analysis of weighted tree means. *Forestry Commission statistics section paper 70*.

22. Josza, L., & Middleton, G. (1994). *A discussion of wood quality attributes and their practical implications.* Vancouver: Forintek Canada Corporation.

23. Keane, T., & Sheridan, T. (2004). Climate of Ireland. In T. Keane, & J. Collins, *Climate, Weather and Irish Agriculture* (2nd ed., pp. 27-58). Dublin: AGMET.

24. Kellomaki, S. (1979). On geoclimatic variation of basic density of Scot's pine wood. *Silva Fenn. , 13* (1), 55-64.

25. Kent, T. (2009). Wood Fuel Quality Testing Methodologies. Presentation made at: Wood fuel Quality and Quality Assurance Workshop, January 21st 2009. Dublin: Sustainable Energy Authority of Ireland & COFORD.

26. Kent, T. (2012). Leveraging additional biomass from the forest resource. *National Bioenergy Conference 2012. Growing the Bio - Economy.* Athlone: Teagasc.

27. Kent, T., Coates, E., & Kofman, P. (2011). *Harvesting wood for energy. An investigation into cost effective wood fuel supply chains from Irish foresty.* Dublin: COFORD.

28. Knaggs, G., & O'Driscoll, E. (2010). *An overview of the Irish wood - based biomass sector in 2007-2009.* Dublin: COFORD.

29. Knaggs, G., & O'Driscoll, E. (2012a). *Woodflow and forest - based biomass energy use on the island of Ireland (2010).* Dublin: COFORD.

30. Kofman, P., & Kent, T. (2007). *Harvesting and Processing Forest Biomass for Energy Production. The Forest Energy 2006 Programme.* Dublin: COFORD.

31. Kofman, P. (2010). *Preview of European standards for solid biofuels.* Dublin: COFORD.

32. Kofman, P. (2012, July). Development of International solid biofuel standards. *Forestry and Wood Update Newletter*, *Volume 12 - No. 2*. Dublin: COFORD.

33. Loibneggar, T. (2011). *Roadmap for implementing standards.* Graz: Intelligent Energy Europe.

34. Matthews, R., & Mackie, E. (2006). *Forest mensuration. A handbook for practitioners* (2nd ed.). Edinburgh: British Forestry Commission.

35. Met Eireann. (2012). *Monthly Data*. Retrieved November 4th, 2012, from www.met.ie: http://www.met.ie/climate/monthly-data.asp?Num=1475

36. Moore, J. (2011). *Wood properties and uses of Sitka spruce in Britain. Forestry Commission research report.* Edinburgh: Forestry Commission.

37. National Forest Inventory. (2007). *National Forest Inventory: Results.* Forest Service. Dublin: Government Publications.

38. Ní Dhubháin, A., Magner, D., & Nieuwenhuis, M. (2006). Juvenile wood in Irish grown Sitka spruce and the impact of rotation length. *Irish For.* , 26-36.

39. Nord-Larsen, T., Bergstedt, A., Farver, O., & Heding, N. (2011). Drying of firewood - the effect of harvesting time, tree species and shelter of stacked wood. *Biomass and Bioen.* , 2993-2998.

40. North, P., Healion, K. (2003). COFORD strategic study - Maximising the potential of wood use for energy. Dublin: COFORD.

41. NREAP. (2010). *National Renewable Energy Action Plan for Ireland.* Dublin: Department of Communications Marine and Natural Resources.

42. NSAI (2009). National Working Agreement 4 : 2009 : Woodfuel Quality Assurance –

Requirements. Dublin: National Standards Authority of Ireland.

43. Nurmi, J. (1993). Heating values of the above ground biomass of small sized trees. *Acta For. Fenn. , 236*.

44. Nurmi, J. (1997). Heating values of mature trees. *Acta For. Fenn.* , 2-28.

45. Obernberger, I., Brunner, T., & Barnthaler, G. (2006). Chemical properties of solid biomass - significance and impact. *Biomass & Bioen. , 30*, 973-982.

46. Phillips, H. (2011). All Ireland roundwood production forecasts 2011-2028. Dublin: COFORD.

47. Premyslovska, E., Slezingeroua, J., & Gandelova, L. (2007). Tree ring width and basic density of wood in different forest types. *Proceedings of DENDROSYMPOSIUM* (pp. 118-122). Riga: TRACE - Tree rings in archaeology, climatology and ecology.

48. Rolls, W. (2009). *Wood as a fuel.* Forestry Commission England.

49. Roser, D., Erkkila, A., Mola - Yodego, B., Sikanen, L., Prinz, R., Heikkinen, A., et al. (2010). *Natural drying methods to promote fuel quality enhancement of small energywood systems.* Joensuu: TEKES.

50. Savill, P. (1979). Rate of weight loss of small round timber. *Irish For. , 36* (1), 48-56.

51. Solid Standards. (2011). Enhancing the implementation of quality and sustainability standards and certification schemes for solid biofuels (EIE/11/218). Utrecht University: The Netherlands.

52. Tobin, B., & Nieuwenhuis, M. (2007). Biomass expansion factors for Sitka spruce (*Picea sitchensis* (Bong.) Carr). *Eur. J. For. Res. , 126*, 189-196.

53. Treacy, M., Everston, J., & Ní Dhubháin, A. (2000). *A comparison of mechanical and physical wood properties of a range of Sitka spruce provenances.* Dublin: COFORD.

54. Ward, D., & Gardiner, J. (1976). The influence of tracheid length and density in Sitka spruce. *Irish For. , 33* (1), 39-56.

55. Wiemann, M., & Williamson, G. (2002). Geographic variation in wood specific gravity: effects of latitude, temperature and precipitation. *Wood Fib. Sci. , 34*, 96-107.

BIOMASS ESTIMATES FOR MOBILISING WOOD FOR ENERGY USING COMPACT RESIDUE LOGS ON HARVESTED CONIFER PLANTATIONS IN IRELAND

Enda Coates and Tom Kent
Waterford Institute of Technology
Cork Road, Waterford, Ireland
ecoates@wit.ie, tkent@wit.ie

Abstract

CRL (compact residue log) bundling is a novel system to Ireland. This study set out to estimate the biomass which can be mobilised on conifer clearfell plantations in Ireland using this method. This study is a part of a larger extensive trial of a residue bundler, the data from seven sites were used in this study. The machine was imported into Ireland from the UK for the duration of the study as no such machine existed in the country at that time. In total, 43 productive hectares were bundled. The bundled oven dry tonnes ranged from 27.3 odt / ha to 46.2 odt / ha, with the mean being 42.4 odt / ha. An average of 11.7 odt was transported per truck load (rigid and trailer). The moisture content variation was large, ranging from a site average of 44% to 62%. The findings of this research has supported the Irish state forestry company in employing a residue bundling machine which has been contracted to work long term in the Irish public forest estate. A second bundling machine has now also started working in the country specifically for the private sector.

1. INTRODUCTION

EU directives have provisioned Ireland with a target of 16% for renewable energy use by the year 2020. It is estimated that this will put demand for forest based biomass at 3,084,000 m^3 (CRDG 2011) However, it is estimated that only 1,453,000 m^3 of forest biomass will be available for the bioenergy market from currently employed supply chains (Phillips 2011). In order to bridge the gap between supply and demand, new systems to mobilise additional wood for energy will need to be employed. CRL bundling may be able to contribute to this gap in supply, but it is a novel system in Ireland, never before being used commercially before this trial.

CRLs (termed compact residue logs, residue bundles, or composite residue bundles) are the compaction and cutting of harvesting residues into cylindrical units (Spinelli & Magagnotti 2009).This is done by the use of a bundling machine which is mounted typically into the back of a forwarding machine. The bundler machine is driven into the forest after all the standard products have been removed, and the remaining residues are collected, compressed and bound with twine into uniform sized units, typically about 3m in length, and in the region of 60 cm in diameter. The bundles are then forwarded out to the roadside and placed into stacks. Road haulage transport to a biomass user is then done with normal timber trucks. At the biomass end user, the bundles are chipped or shredded for use in their boiler (Rummer et al. 2004). A slightly different supply chain is where the bundler is truck mounted, where residues are brought to the roadside loose by a forwarder, and then bundled. The benefits of bundling the residues is that the bundles are uniform discrete units which can be described (bundle counts, and weights) and the supply chain uses existing forestry systems of supply (forwarders, truck transport). Bundling also compresses the residues, so forwarding, road transportation, storage, and handling of the residues is more cost effective (Spinelli & Magagnotti 2009).

Standard forestry measurement practices estimate standing trees to merchantable timber height, typically where the stem tapers below 7cm diameter (Matthews and Mackie 2006), as this is typically the stem section used by saw mills and panel board mills. There is therefore a need for estimates of the residue material that exists in addition to the merchantable stem.

The aim of this study was to quantify the biomass that mobilised during a trial of bundling residues on conifer clearfell plantations in Ireland. The goal of the analysis was to quantity the biomass in three domains:

i) an individual bundle
ii) a truck load of bundles
iii) a productive hectare residues for bundling

This study is an output of a collaborative trial between Waterford Institute of Technology (a university level institute in Ireland) and Coillte (the Irish State forestry company). The end user of the material was Medite, an MDF plant situated in the south east of Ireland. Medite shredded the bundles for use as boiler fuel in its manufacturing process

2. METHOD

Seven trial sites were used in this study. All sites consisted of plantation conifer high forest made up of a single species, Sitka spruce (Picea sitchensis). Finasl felling was cut to length roundwood harvesting to 7cm top diameter. The biomass estimates are based on empirical measurements detailed in this document, and an estimate of net productive bundled area on these specific sites from a report by Neri (2012) who also worked on this residue bundling trial. The report by Neri includes additional sites that were not part of this study. It was decided to keep the same site numbering system used by Neri as reference can then be easily made between the two studies.

The seven trial sites were located in the south east of Ireland, in proximity to the end user, Medite, an MDF plant with a large requirement for biomass heat. Figure 1 shows the site locations, Table 1 details the site characteristics.

Figure 1: Site locations used in the study.

Table 1: Pre timber harvesting site inventory and characteristics.

Site Number	Location	Age	Trees/ha	Vol/ha (m3)	Mean tree vol. (m3)	Average dbh (cm)
1	Knockanore	39	477	473	0.99	34
3	Knockanore	50	610	467	0.77	30
5	Mellory	42	969	464	0.48	26
7	Mellory	43	566	434	0.77	31
8	Dungarvan	45	1018	420	0.41	25
9	Kilmacthomas	46	510	432	0.85	33
11	Dungarvan	45	429	343	0.8	31

As there was no residue bundling machine in Ireland at that time, a machine was contracted in from Scotland to perform the work. The machine was contracted to produce bundles with dimensions in the region of 2.5 m in length, and 60 cm diameter. It had been initially planned that the bundler would make 3 m length bundles, but it was quickly found that 3 m length bundles were insufficiently rigid and fell apart as the residue material consisted of short tops and branches. This was because the roundwood had been cut to 7 cm top diameter, so there were very few log stem parts in the remaining brash. Between the 11th of March and the 19th of August 2010, 153 truck loads of these bundles were delivered from these sites into Medite. The net weight of each load was recorded at the weigh bridge, and a count of the bundles on each load was also taken. In order to asses the moisture content of the bundles, a number of samples were taken after the bundles were shredded with a Jenz 640 shredder at the plant. A subset of the bundles at the plant were also measured for dimensions and moisture content individually.

The formula that were used in this study to characterise and estimate the biomass values are detailed below:

Moisture content was calculated on a wet weight basis as follows:
Moisture Content (% total weight) = [(Ww – Wd) / Ww] * 100
Where:
Ww = Wet Weight
Wd = Dry Weight

Dry mass was calculated from the total bundle weight and bundle moisture content, as follows:

W(dm) = W(g) * [(1 - (MC% / 100)]
Where:
W(dm) Dry mass in kg
W(g) = Bundle Weight in kg
MC% = Bundle moisture content expressed as a percentage of total weight

Bundle oven dry density was calculated as follows:

D(od) = W(dm) / V
Where:
D(od) = Bundle oven dry density in kg/m^3
W(dm) = Dry mass in kg of a bundle

V = Volume of a bundle in m^3

3. RESULTS AND DISCUSSION

3.1 Characterisation of individually measured bundles

On delivery of the bundles to the end user, the length, mid diameter, weight, and moisture content measurements of 20 bundles per site was planned. Unfortunately it was not possible to take all these measurements due to the working conditions at the plant, and only a portion of dimensional and weight measurements could be taken. The procedure involved measuring the length of a bundle with a tape measure, the diameter with a diameter tape, and the weight using a pallet truck with a load cell attached. Table 2 shows the observed dimensions of the sampled bundles. Overall, the average bundle length was 2.6 m, and the average diameter was 76 cm. The overall average volume of a bundle was 1.19 m^3.

Table 2: Dimensions and volume estimate of individually measure bundles.

Variable	Site number	n	Mean	StDev	Minimum	Maximum
Length (cm)	3	19	264	12	247	293
	5	11	262	16	249	304
	7	20	258	4	251	266
	9	18	248	8	236	262
	11	7	255	6	244	262
Mid-diameter (cm)	3	19	76	4	68	83
	5	11	76	4	72	85
	7	20	73	4	67	80
	9	18	78	4	71	89
	11	7	80	3	74	84
Volume (m^3)	3	19	1.19	0.13	0.98	1.40
	5	11	1.20	0.13	1.05	1.43
	7	20	1.08	0.10	0.92	1.28
	9	18	1.18	0.14	0.99	1.56
	11	7	1.28	0.12	1.09	1.45

Each bundle was then shredded into hogfuel separately, and three samples of approx. 1 kg were taken for moisture content determination using the oven dry method at 105 degrees Celsius. The moisture contents were then used with the bundle weights to estimate dry mass per bundle. Table 3 details the dry mass results of the bundles measured.

Table 3: Dry matter estimates (kg) of individually measured bundles.

Site number	N	Mean	StDev	Minimum	Maximum
3	19	194	27	149	248
5	11	169	19	148	201
7	20	189	21	161	231
9	18	188	25	139	252
11	7	211	19	187	232
Average		**190**			

The mean dry mass per bundle overall is estimated as being 190 kg per bundle. The data shows that the overall range of both highest and lowest was observed in samples taken from site number 9 with figures of 139 kg to 252 kg. A similar large range is found in the other sites, indicating a large variability in bundle composition. To investigate this further, a comparison between the sites was made using simple statistical tests. Firstly however, it was decided that only site numbers 3, 7, and 9 were to be used in the analysis as they have an acceptable sample size for the tests. A normality test showed that all three data sets were normally distributed at an alpha level of 0.05. The normal probability plots are detailed in Figure 2 below.

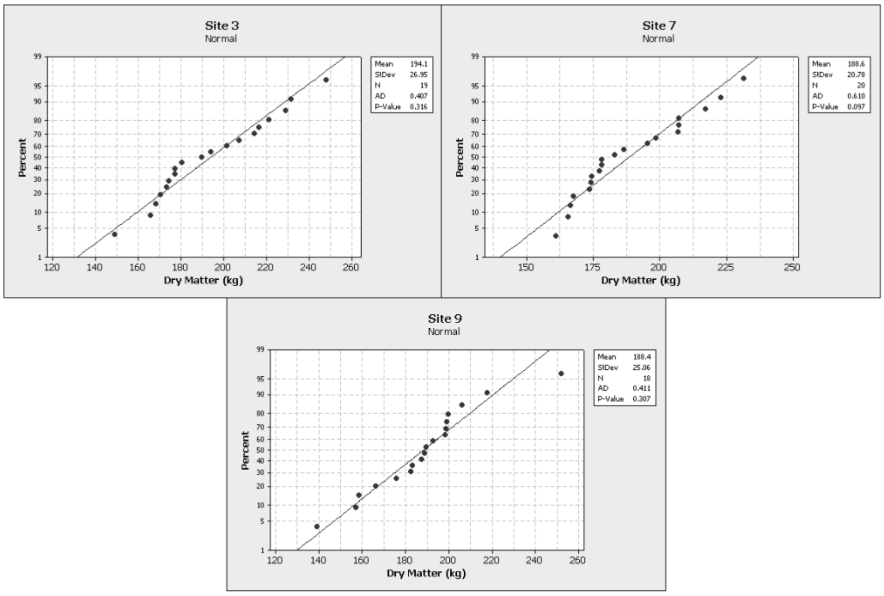


Figure 2: Probability Plot of Dry Matter per Bundle (kg) on the three tested sites.

An analysis of variance between these three sites shows that there is no statistical difference between the mean dry matter per bundles on the sites (at an alpha level of 0.05). This suggests that between these sites, a difference was not detected that affected the quantity of dry mass that was site specific. An investigation into the variability of the dry matter per bundle due to the variation in machine operation and other parameter factors was investigated. It was thought that perhaps variation in the length, diameter, or moisture content was affecting the dry matter per bundle, as the length and diameter is a function of the size of an individual bundle, and the moisture content contributes to the overall weight and possibly handling capabilities of the brash.

A regression analysis was used to identify if these variables had an impact on the dry mass per bundle. The results of the analysis for each variable is shown in Table 4.

Table 4. Regression analysis results for the individually measured bales.

Variable	P	R2
Length (cm)	0.389	0.0000
Mid diam (cm)	0.023	0.0739
Moisture content %	0.945	0.0000

It was found that neither length or moisture content had any significant correlation at an alpha level of 0.05. The variable of mid diameter showed to be statistically significant, however the R^2 value is very low at 7%. Also, one large residual, an outlier on the x-axis, has a powerful effect on the results. Removing this one data point and re running the regression gave an r^2 of 0%, showed a no statistically significant relationship.

The analysis suggests that on these study sites, the large variability in dry mass per bundle cannot be attributed to the site, variability in the length and diameter, or moisture content of the bundles. It is probable that the range of the dry mass per bundle is largely affected by the piece size of the brash going into each bundle eg.Oarticle size and particle type distribution, proportion of large stem pieces, and wood, bark, and needles. An evaluation of the brash characteristics within the bundles was outside of the scope of this study. These findings suggest that the variability of the dry mass per bundle would not have been reduced by tighter control of the bundle dimension (settings on the machine).

It may be useful to be able to estimate the dry mass per bundle if the length parameter is changed by the machine operator, for example: no longer cutting to 2.6 m length, but to 3.0 m. This can be estimated by the use of a bundle oven dry density estimate. Using the dimension and dry mass data, the oven dry density of the bundles observed in the study is estimated as 162 kg / m3. A summary of the estimates is given in Table 5. This suggests that if the operational settings of the bundler were changed to cut the bundles on average to a length of 3m, with the average diameter remaining at 76 cm, the bundles would have on average a dry mass of 220 kg.

Table 5: Bundle oven dry density results of the individually measured bundles.

Variable	Site number	N	Mean	StDev	Minimum	Maximum
Bundle Oven Dry Density (kg/m^3)	3	19	163	21	122	208
	5	11	143	27	107	191
	7	20	176	23	131	221
	9	18	162	26	103	220
	11	7	165	11	144	174
	Average		**162**			

3.2 Individual truck measurements from the sites

The weight of every truck from the trial transported to the plant was recorded on a weigh bridge on arrival. Unfortunately site no. 3 had gaps in the data and was removed from the analysis. Along with the weight information, the site which each truck was transporting from was recorded, and the number of bales on each truck. In order to get an estimate of the dry mass delivered on each truck, moisture contents were taken at delivery. This was done as the bundles were being shredded once unloaded in the yard. The samples were analysed using the oven dry method at 105 degrees Celsius. Unfortunately, because of the working conditions at the factory, it was not possible to get individual moisture contents for every truck. It was only possible to get a sample of moisture contents from each site. It was planned that 60 moisture content samples were to be taken per site, although some had fewer (the lowest being 30 samples). Table 6 details the moisture content results.

Table 6: Moisture content results from shredded bundles.

Variable	Site Number	N	Mean	StDev	Minimum	Maximum
Moisture Content %	1	30	56	4	46	64
	5	59	53	8	20	64
	7	59	59	5	47	67
	8	30	54	4	46	64
	9	60	42	9	22	58
	11	59	44	6	29	65

It was found that moisture contents taken from the shredded bundle material had a large range, from 22% at the lowest value to 67% at the highest. The high values were reflected within each site, as each site had samples upwards of 55% moisture content. The lower moisture content levels were observed only on three of the six sites. The data points are illustrated in Figure 3. This large variability in moisture content within sites suggests unequal drying of the brash post harvesting and/or bundling, but any further analysis is outside of the scope of this paper. A separate paper from this residue bundling trial is on the monitoring of moisture content change of bundles in storage over time using automated weighing systems, and these results can be viewed in the paper by Kent & Coates (2011). The results in that paper reveal large variations in moisture content within stacks of bundles even after a summer storage period.

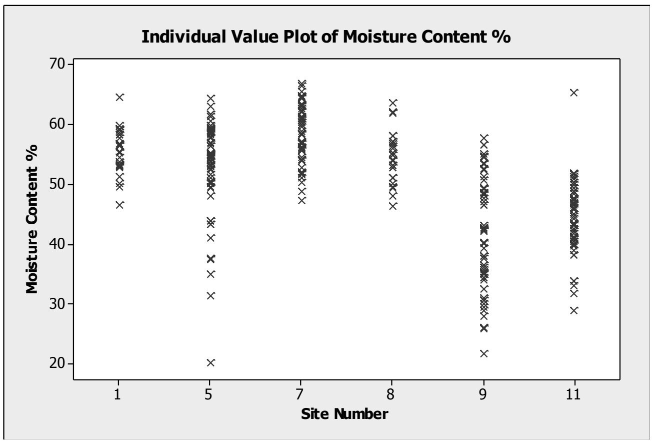


Figure 3: Data points of shredded bundle moisture content samples from the trial sites.

The mean moisture content of each site was applied to the truck weights transported over the weighbridge at the end user to estimate the dry matter per load. The mean dry mass per truck, number of trucks, and mean number of bundles are detailed in Table 7.

Table 7: Mean dry mass estimate and number of bales per truck.

Variable	Site Number	No. of Trucks	Mean	StDev	Minimum	Maximum
Dry Mass (kg)	1	34	12752	821	10542	14281
	5	31	12388	712	11074	13630
	7	14	11049	1072	8139	12241
	8	38	11327	964	8730	13082
	9	19	12559	1560	9289	15080
	11	17	12848	970	11132	14116
No. bales	1	34	65	4	57	74
	5	31	59	4	47	65
	7	14	62	6	44	67
	8	38	67	3	54	72
	9	19	66	5	56	72
	11	17	61	5	50	67

In total, 153 trucks were observed in the study. The number of trucks per site is related to site size. The mean dry mass per truck is relatively similar across all sites. The mean truck weight per site ranges from 11.0 odt to 12.8 odt, giving an overall average of 12.2 odt (12153 kg). On an individual truck, the lowest weight of odt transported during the study was 8.1 odt, the highest was 12.8 odt. Analysis was run to investigate whether a specific trucks / drivers (identified by vehicle registration) were affecting the load sizes. This did not bear any significant results. Unfortunately, the moisture content samples could not be related directly back to the specific trucks to give more accurate results.

On average, there were 63 bundles transported per load.

3.3 Site estimates for biomass removed using CRL bundling

The estimates of each individual truck was used to estimate the total odt mobilised from each site. This was simply the total sum of all truck loads. This data was used with the site description and inventory data, and data from a study by Neri (2012) to estimate the biomass mobilised per hectare. Neri’s study included these specific sites during this trial. The study focussed on estimating the actual area bundled on each site, and identified explanatory reasons why the biomass was not removed from certain parts (i.e. unproductive areas). The total biomass mobilised, the total site areas, the productive areas (from Neri 2012), and the biomass mobilised per productive hectare are detailed in Table 8.

Table 8: Biomass estimates per productive hectare.

Site Number	Total odt	Harvested Area (Clearfell) ha	% of Harvested Area Bundled*	Bundled (net productive) Area ha	odt per Bundled (net productive) ha
1	433.6	15.1	66	9.9	43.8
5	384.0	10.9	77	8.4	45.7
7	154.7	9.2	41	3.8	40.7
8	430.4	9.8	95	9.3	46.3
9	238.6	9.3	75	7	34.1
11	218.4	20.5	24	5	43.7
Average					**42.4**

*Figure estimated by Neri (2012)

The data gives a range of 34 to 46 odt delivered to the end-user per productive hectare. The data from the different sites is relatively consistent, and shows no large outliers. The overall mean is estimated as 42.4 odt per productive hectare. The total number of bales per site delivered to the end user, and the total biomass delivered to each site gives an estimate of mean bundle dry mass of 193 kg, which diverges from the estimate from the individual bundle measurements (190 kg) in Table 3 by only 3 kg. This data is illustrated in Table 9. Although these are robust total figures for the six sites, the small number of sites means that further analysis of the data is difficult. Regression analysis using the pre-harvest forest parameters values as independent variables to describe odt per productive hectare was attempted, but none were seen to be significant. The distribution of the data could not be described either, as the small sample size may lead to type II errors. However, this small sample size enabled the robustness of the total biomass estimate on each site. For better analysis of the impacting factors on the odt per productive hectare, it may have been beneficial to divide the sites into working plots to get a larger data set. However this would have come with a cost of sampling error that may have reduced the accuracy of the total figures.

Table 9: Total biomass (odt) and number of bundles produced during the study.

Site number	Total odt	Total number of bundles	Average Bundle dry mass (Kg)
1	433.6	2197	197
5	384.0	1818	211
7	154.7	870	178
8	430.4	2527	170
9	238.6	1248	191
11	218.4	1045	209
Average			**193**

4. CONCLUSIONS

The biomass estimates gained from this paper are the first of their kind in Ireland. The estimates are based on large scale industrial trials that were undertaken in conjunction with the Irish state forestry company Coillte. A mean value of 42.4 odt per productive hectare has been estimated for the clearfell conifer plantations that were trialled in Ireland. The range of the estimates was from 34 to 46 odt per productive hectare. There is a caveat to this estimates. If using them for estimating the potential biomass from CRL bundling on different sites, the productive hectarage of those sites must be estimated. For the proceedure used to asses the trial sites, see Neri (2012), however this was post bundling. It must be noted that future estimates will most likely involve two reductions: a reduction from total site area to harvestable area, and a reduction from harvestable area to area suitable for bundling. The authors have engaged in a piece of research work which trialled different methods of harvester clearfelling that facilitated brash presentation for bundling. The study involved productivity studies of the harvester, forwarder extracting roundwood, bundler, and the forwarder extracting bundles, as well as fuel characterisation and quality analysis. Future work with this data should allow for reccommendations on methods that could benefit the supply chain as a whole. .

A mean dry mass for bundles being produced with dimensions of 2.6 m length, and 76 cm diameter was estimated at 190 kg. This estimate was later verified by the total number of bundles from the study as a whole (9705) and the total odt received over the weighbridge (1860 odt) giving an etimate that was less than 1.6% in difference. An oven dry density estimate of the bundles based on the this data was estimated at 162 kg/m^3. These robust figures may be useful for future practitioners in planning and estimating residue bundle logistics.

The findings of this research has supported the Irish state forestry company in employing a residue bundling machine which has been contracted to work long term in the Irish public forest estate. A second bundling machine has now also started working in the country specifically for the private sector. Future work on the residue bundles that is currently being undertaken are:

- the development of a supply chain productivity and cost model from empirical data gathered in Ireland that will allow for interrogation and sensitivity analysis of parameters in the system.
- drying models using data from past and future drying trials to allow prediction of the bundles moisture content over time

- the characterisation of the fuel quality parameters of the hogfuel that is produced from shredding the bundles
- the development with Medite of a proceedure for measuring the delivered energy content of the bundles for payment purposes as they arrive at the plant

ACKNOWLEDGEMENTS

This work is part of the Forest Energy 2010 – 2014 Research Programme funded by the Department of Agriculture, Food and Fisheries Competitive Forest Research and Development Programme, supported under the National Development Plan 2007-2013.

This work was carried out in collaboration with Mr. Mick Fenton, Coillte, Mr. Pat O' Connor Medite and Mr. Robert Power, University of Limerick. Many thanks to Mr. Cathal Hennessy, Coillte. Thanks to all others that facilitated this work.

REFERENCES

CRDG: Coford Roundwood Demand Group (2011) *All Ireland Roundwood Demand Forecast 2011-2020,* Dublin, Ireland, COFORD.

Kent, T. Coates E. (2011) Monitoring the drying of residue bundles during storage in the forest and at a terminal in Ireland. Proceedings of 44th International Symposium on Forestry Mechanisation, Graz Austria.

Matthews, R. W. & Mackie, E. D. (2006) *Forest Mensuration: A Handbook for Practitioners,* Edinburgh, Forestry Commission.

Neri, Francesco (2012). Energy Value of Forest Residue Bundles. *Forest Energy Observer.*

Phillips, H. (2011) *All Ireland Roundwood Production Forecast 2011-2028*. COFORD, Department of Agriculture Fisheries and Food, *Dublin*.

Rummer, Bob, Dan Len, and Obie O'Brien (2004). "*Forest residues bundling project: New technology for residue removal*." US Forest Service, Missoula Technology Development Center.

Spinelli, R. & Magagnotti, N. (2009): Logging residue bundling at the roadside in mountain operations, Scandinavian Journal of Forest Research, 24:2, 173-181.

ROADSIDE CHIPPING: KEY POINTS

CEO Tommi Lahti and Pierre de Bie, LHM Chipper Ltd., Finland

Kotimaiset Energiat Oy, owned by Tommi Lahti, has got more than 40 years of experience in roadside chipping of forest chips in Finland but also in Baltic states and France.

In 2011 nearly 10 % of all forest chips(except stumps) were treated by Kotimaiset Energiat Oy, this means about 1 TWh of energy created.

What are the general requirements along Kotimaiset Energiat Oy for successful roadside chipping of forest residues?

- Enough feedstock : the buyers of woodchips should have enough capacity of forestresidues for the whole year, so that the chippercompany has got enough work for the whole year.
- the right forest chipper: fast, mobile and powerful truckchipper . LHM Chippers Ltd makes powerful and reliable mobile drumchippers that are bigsized but still small enough to handle into narrow forest roads!
- Quality of feedstock: The piles of forest residues should be high and long enough and well situated along the forestroads. They should be protected by papercloth and well aired. They should be easy to reach by chipper and trailer.
- Good forest roads: reachable network the whole year round and supports the truck loads of more than 60 tons! Roadside Chipping: Keypoints

- Finnish forests and woodfuels at a glance
- Who we are: LHM Hakkuri& Kotimaiset Energiat
- Forest chips: what?
- Moisture Content & Profitability
- Anatomy of roadside chipping
- Good stockpiles
- Opportunities and Threats

PRECISION SUPPLY OF FOREST BIOMASS TO COMBINED HEAT AND POWER AND BIO-OIL PLANTS

Perttu Anttila, Johannes Windisch, Kari Väätäinen, Antti Asikainen, Mikko Nivala & Juha Laitila*

Finnish Forest Research Institute, Yliopistokatu 6, 80101 Joensuu, Finland,
johannes.windisch@metla.fi, perttu.anttila@metla.fi, kari.vaatainen@metla.fi,
mikko.nivala@metla.fi, antti.asikainen@metla.fi, juha.laitila@metla.fi
**corresponding author*

The procurement of forest biomass for energy underlies seasonal changes, both in quantity and quality. The demand of combined heat and power plant is highest in the wintertime, whereas the demand in bio-oil plants is more or less constant throughout the year. Fleet capacity of the supply chain and conditions on small roads may restrict procurement in winter and the moisture of biomass is higher than in summer. The problem of seasonal fluctuations can be partly addressed by buffer storages, but storing of biomass adds to capital costs. Precision supply (PS), which means supplying the requested quantities of material of the right quality at the right time, has been proposed as means to lower costs of biomass procurement and utilisation.

The objectives of this study are to evaluate the potential of the PS approach in 1) reducing supply costs and 2) alleviating the seasonal fluctuations in the utilisation rate of machinery. The case study will present a case from Finland where the PS approach is compared to the "business as usual" (BAU) with discrete-event simulation. In the BAU scenario the quality characteristics of the delivered lots are not known and the selection of piles is based on first-in-first-out procedure.

The PS approach tries to minimise the supply cost and balance the labour and machinery need by supplying dryer material from shorter distances using higher class roads in winter and wetter material from longer distances and smaller roads in summer. To achieve this, a more comprehensive use and more precise handling of available information will be simulated and its effects on the functioning of the supply chain and the cost structure of the procurement process will be studied. Drying models are used to predict the moisture content of the material what facilitates better logistical planning.

The results will show potential benefits of PS by comparing its cost structure to the BAU scenario; in particular, the differences in

- Machine costs: including investigation of machine utilisation rates and relocation costs
- Transportation costs: including investigation of road maintenance costs (e.g. snow ploughing) and total driven kilometres per MWh
- Overall procurement costs per m3 and MWh
- Calorific value and creation of value per m3
- Time element distribution of each machine
- Energy balance
- Carbon footprint.

The results of the study will be available by June. An oral presentation is preferred.

APPLYING GEOGRAPHICAL OPEN-ACCESS DATA IN THE ANALYSES OF FOREST-FUEL SUPPLY LOGISTICS

O.-J. Korpinen & T. Ranta
Lappeenranta University of Technology
Sammonkatu 12, 50130 Mikkeli, Finland
olli-jussi.korpinen@lut.fi

ABSTRACT: Advanced studies of biomass supply chains require geographical data about biomass sources and transport networks. Earlier studies have shown that power plants with equal biomass demand may have significant differences in the biofuel supply chains' economic profitability and environmental impacts, even inside the same country. This is important especially in cases with large-scale biomass demand. Availability of public GIS data in Northern Europe and requirements for datasets' properties was explored in this paper. The performance of different data sources was evaluated in a case study from Finland and Sweden. According to the data review there are significant differences in the quality of available GIS datasets. However, the results of the case study indicate that, regardless of data quality, it is important to include GIS data also from neighboring countries if the supply area is expected to cross national borders.

Keywords: forest fuels, transportation, geographical information system (GIS)

1 INTRODUCTION

Increasing use of bioenergy in Europe calls for advanced studies about the economy and sustainability of biomass production and supply. A geographical standpoint is usually included in the analyses of feedstock supply because the biomass sources tend to be geographically widespread, and the spatial variation in biomass productivity and availability may be significant. In general, agricultural land in the densely populated areas and forests in the rural areas stand for the greatest part of energy biomass production in Europe. Supply of forest fuels, which is the most important primary biomass feedstock in Nordic countries, includes a complex network of origin points, demand points and intermediate storage points. Geographical Information Systems (GIS) based analyses about biomass availability are important especially in regions where several fuel suppliers compete for the same type of feedstock.

The authors of this paper have previously designed a GIS model serving the economic analysis [1] and the evaluation of greenhouse gas (GHG) emissions [2] of forest-fuel transportation. The calculation model is based on a geographical grid, where the middle points of the grid cells link data layers of biomass availability with transport network layers (Fig. 1). A minimum requirement for transport network layer is a road network dataset in vector format. Waterways and a rail network can be added to the model as additional layers. A biomass source-data layer shall be a single layer or a combination of several data layers. Biomass availability estimates are connected to the grid points by an allocation method described in [1] and [2].

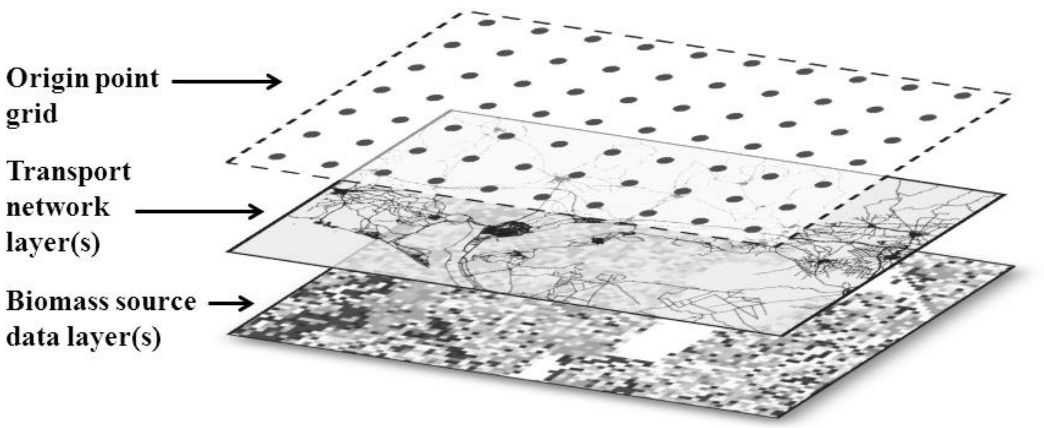


Figure 1. Geographical data layers of a forest-fuel availability and supply analysis [1].

The GIS model has been developed for analyzing domestic forest-fuel supply in Finland, but it could be applicable for other regions as well. Nonetheless, geographically accurate source data about the study area is needed, and those data meeting the case might be difficult to acquire. A major reason is that collecting both forest-resource and transport-network data from a large area (e.g. a country) is laborious and possible only for large organizations. Thus, data providers are only few and datasets may be expensive. Forest resource data is typically collected in public-funded forest inventories, while transport network data are provided by, e.g., both private software companies and national mapping agencies (NMA).

NMA-mapped topographic data usually contain the most accurate and uniform information about transport networks within one country. Despite the fact that still the majority of European NMA's charge license fees for the release of public-funded data, some NMA's have opened datasets for free access, including commercial use (Fig. 2). These have been important decisions especially for small and medium-sized enterprises (SME) that generally are incapable of purchasing large and expensive geographical datasets [3].

The governmental measures of releasing European GIS data to open-access are, to a large extent, based on INSPIRE directive [4] that includes the guidelines of enhancing the availability of spatial data and interoperability between the datasets. Despite the recent development, European countries still have their own standards for., e.g., road network data. In transnational analyses this often means that manual data processing is needed for including different types of datasets into one GIS model.

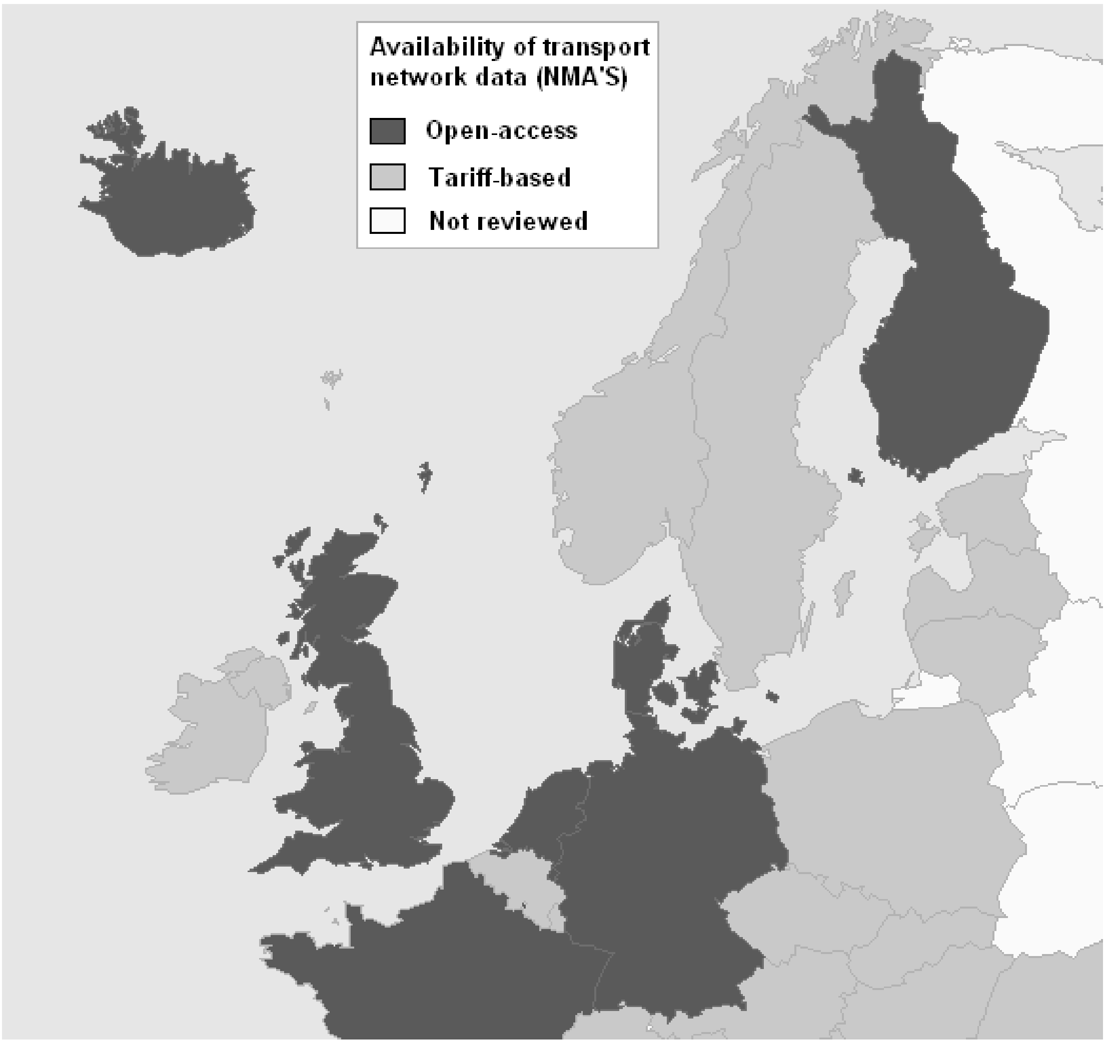


Figure 2. Availability of free transport network data[1] in vector format provided by the national mapping agencies (NMA's) in Northern Europe in May 2013. Open-access licence terms vary between the countries.

[1] Several NMA's provide free vector maps containing only the main roads. It was presumed that the data includes also rural road network.

An alternative method is to use a data service being based on voluntary work in data collection and management. Such an online-service is OpenStreetMap (OSM) [5], which has been available since 2006. OSM serves nowadays a weekly-updated planet file and country-specific extracts to be downloaded as shapefiles[2]. OSM data is available for all European countries. However, local availability and accuracy of road data is usually better in densely populated areas than in the countryside. From the biomass logistics' point of view this is an important issue, because the origins of biomass supply chains tend to be in rural areas. OSM's advantage is that one dataset can be easily applied for a case study covering several countries.

The availability and quality of national forest resource data varies widely across the Europe. It is characteristic that in the countries where forest coverage is sparse or forests are less important to national economy, also public transfer services of forest data are poorer than the corresponding services in more forested countries.

However, some exceptions exist. For example, Great Britain with only ca. 10% coverage of woodlands [6] provides a data-transfer service, where one can freely download almost up-to-date national forest inventory (NFI) data directly in a geographical information (.shp) format [7]. A similar service is also provided in Norway, which has ca. 40% forest coverage [8].

Among the majority of the reviewed countries (Fig. 2), NFI reports are published online only in text format (e.g. Adobe PDF or HTML) or spreadsheets. In these cases, importing data into the biomass calculation model is demanding. The inventory results are usually broken down into small regions that have to be manually connected to the GIS layer including administrative boundaries of the country (e.g.[9]). Regional figures can be further allocated to the origin points by calculating forest coverage values from remote sensing data. For example, CORINE Land Cover (CLC) is a useful GIS-dataset in the allocation of the NFI results into the origin points of the model. CLC is a combination of automatically interpreted high-resolution satellite images, and the data is available in both raster and vector format [10]. One of CLC's advantages is that it can be used nearly everywhere in Europe, and especially in international analyses. On the other hand, similar national datasets may give more reliable information, in terms of both land-use classification and geographical accuracy.

2 CASE STUDY

2.1 Purpose of the study

In this study different GIS datasets were taken into use for analyzing forest-fuel availability and transport possibilities in the northern territories of Finland and Sweden. The demand point in the case was Kemi, Finland[3] (65°40′0″N, 24°33′0″E), which is a suitable location for a large-scale refinery producing second-generation liquid biofuels from solid forest biomass [11]. Kemi-centred forest-fuel supply chains have also been studied earlier in comparison with two other possible plant locations in Southern Finland, i.e. Porvoo (60°18′0″N, 25°32′0″E) and Rauma (61°07′0″N, 21°28′0″E) [12]. However, biomass supply from abroad was not included in the previous study. Besides the fact that all of the studied locations could receive marine deliveries, the study also left an open question about how much Swedish forest biomass could be supplied by road to Kemi. The closest border-crossing point is only ca. 30 km by road from Kemi. The purpose of this case study was to evaluate how biomass transport distances to Kemi plant would change if Swedish forest resource and road network data were included in the GIS model. This study included only small-diameter energy wood (SDW) supply and excluded other forest-fuel sources, such as logging residues and stump biomass. The software being used was ArcGIS 10 Professional with Network Analyst extension.

2.2 Material and methods

A 4 km × 4 km origin point grid covering the northern parts of Finland and Sweden was used to link the biomass source data with transport network data. In this case, only road network was used for transportation. The Finnish origin points and their SDW availability estimates were extracted from the previous study [12]. Based on that study, it was assumed that the plant could have access to 50% of the techno-economic potential of SDW, which was 13 TWh/a for the whole country.

Biomass availability data from Sweden was acquired from a Swedish NFI based study reporting the biomass resources of young forest stands [13]. It had been concluded that from the whole country ca. 27 TWh/a could be harvested, of which 59%, i.e. ca. 16 TWh/a could be harvested from the northernmost part of Sweden (i.e. Norrland)[4]. This estimate was also cut by 50%, standing for the supposed SDW availability to Kemi plant.

A CLC dataset from Sweden was used in allocating the biomass availability potential into the origin points. A point was given a value between 0 and 1 according to the proportional forest coverage of the 4 km × 4 km square around the point. This value was used as a weighting coefficient for a single point when calculating itsshare of total availability. Despite the fact that logging restrictions are applied in some forested areas due to, e.g., nature conservation or military purposes, such restrictions were not included in this study.

For annual SDW demand, two scenarios were

[2] Esri shapefile is a commonly used format to store and transfer geographical data.

[3] Also designated as Ajos, the harbour of Kemi.

[4] Original results were converted by a coefficient of 5.4 MWh per ton of dry matter.

used: 1 TWh and 2 TWh. The road transport analysis was conducted in two parts: 1) NMA network based and 2) OSM network based analysis. Both networks were built by combining road network datasets from Finland and Sweden. In the NMA network based analysis, Finnish road data were acquired from the Topographical database of National Land Survey of Finland [14]. The Swedish dataset was the most extensive open-access dataset being provided by the corresponding NMA, Lantmäteriet [15]. Small forest roads were not included in that dataset. In the OSM data based analysis, the data were country-specific extracts from the OSM planet file.

Geographical properties of the study area, road network datasets and biomass availability data allocated to the origin points are presented in Fig. 3. Because of differences in the quality of source data, the border between Finland and Sweden can be observed in the maps presenting the NMA road data and biomass availability data.

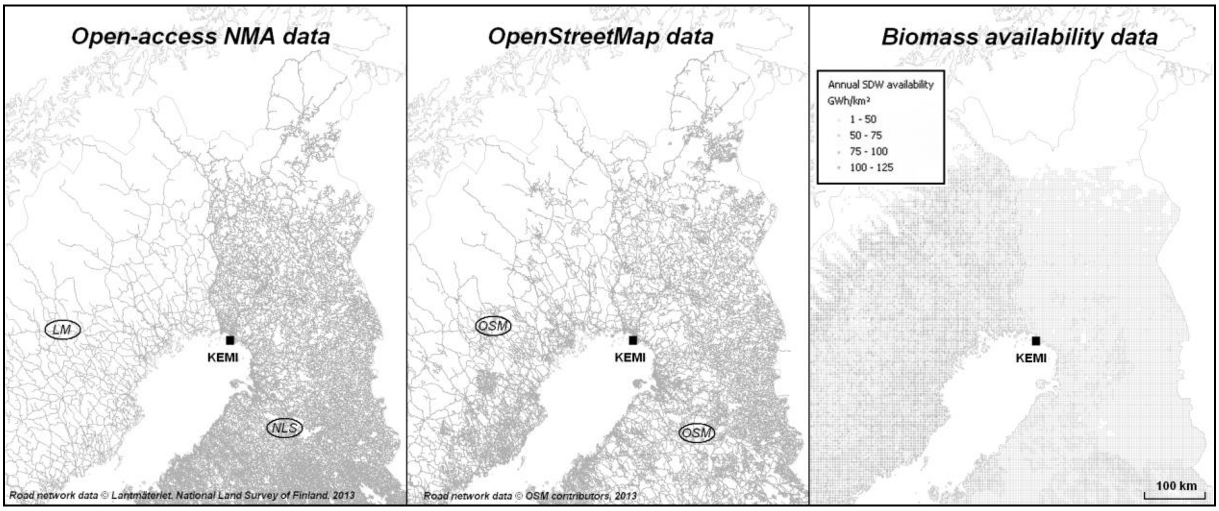


Figure 3. Transport network and biomass availability data used in the analyses of small-diameter energy wood (SDW) supply to Kemi. The first analysis (left) was conducted with the most detailed road data provided free of charge by the national mapping agencies in Finland (NLS) and Sweden (LM). In the second analysis (middle), OpenStreetMap (OSM) data was used.

2.3 Results and discussion

The annual demand for 1 TWh of SDW biomass was fulfilled in NMA data based analysis when the maximum transport distance was 187 km. Accordingly, 2 TWh/a availability volume was met in 259 km. In OSM based analysis the supply-area radii were 195 km and 265 km, respectively.

Supply-area maps of the two analyses are presented in Fig. 4. Road geometry of OSM data was less coherent than the NMA data, which is indicated by "holes" in OSM data based map. This also explains, to some extent, longer transport distances in OSM data based analysis. However, in both analyses ca. 20% of all origin points were passed over because the calculation model could not locate the points more than 1 km off the road network [2]. The loss of points was significant especially in Sweden, where the road network was sparse regardless of the chosen data source (i.e. NMA or OSM). In OSM based analysis, 60% of the "unlocated" origin points were from Sweden and 40% from Finland, while the respective shares were 90% and 10% in NMA based analysis. On the other hand, a majority of the lost points are presumably at the less forested mountain areas. Therefore, the loss in supply potential could be expected to be less than 20%.

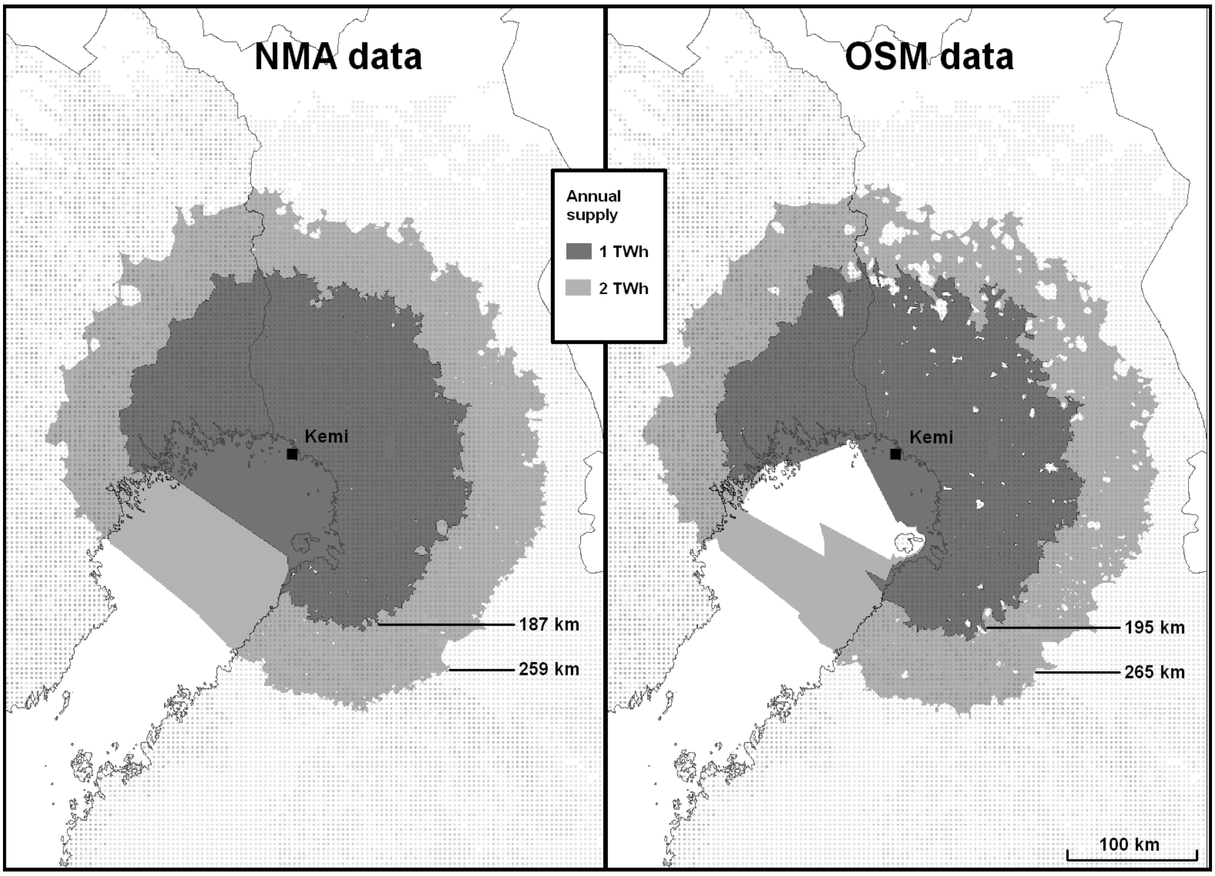


Figure 4. Supply areas of SDW according to the road data used in the case study.

The increase in average transport distances was 3-7% when using OSM data instead of NMA data. This can be considered as a small difference if the results are compared with previously presented GIS based calculation methods. For example, the results of the earlier study with similar limitations in forest-fuel availability [12] indicate that ca. 30% less SDW is available within 250 km transport distance if only Finnish origin points are included in the analysis.

If the analysis was based only on straight distances (i.e. geodesic distances) from the origin points to the demand point, the availability would be evidently higher. These figures can be adjusted with winding factors estimating average road network properties in certain regions. According to Ranta [16], the winding factor in Northern Finland is 1.31. The compared calculation methods are presented in Fig. 5. It can be assumed that if the calculation of supply areas did not miss any of the origin points, the NMA data based availability would be closer to the availability estimate based on winding factor method.

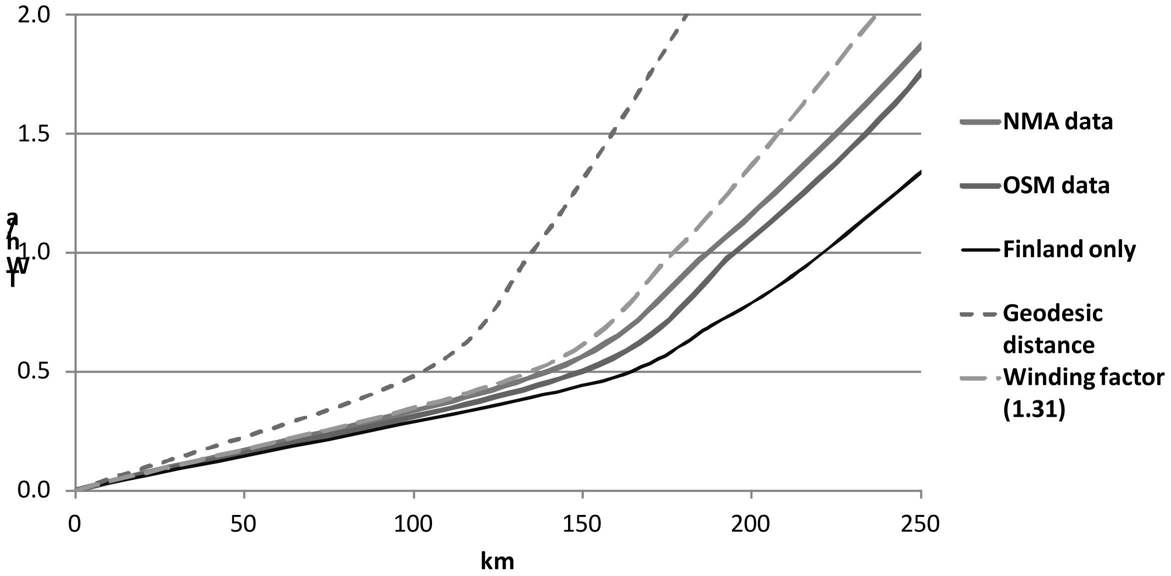


Figure 5. The availability of SDW to Kemi according to the supply-area radius. "Finland only" refers to the results of a previous study focusing on Finnish transport network [12]. "Geodesic distance" is a theoretic scenario including only straight origin-destination distances and excluding road network data. In "Winding factor" scheme, the geodesic distance was multiplied by a coefficient (1.31) suitable for roads of Northern Finland [16].

3 CONCLUSIONS

The purpose of the case study was to experiment the applicability of the GIS model and spatial data in a transnational analysis about forest-fuel supply and demand. Depending on total biomass demand, the OSM data caused ca. 3-7% smaller estimates of biomass availability than the NMA data. The results should not be generalized across the entire Europe because the quality of both OSM and NMA data varies greatly in different parts of the continent. A general conclusion is that, in addition to the highlighted countries in Fig. 2, opening of high-quality NMA data in the rest of Europe would improve the transport analyses universally. In Sweden this would mean that the road geometry included in the national road database, NVDB [17], was released for open use.

In comparison with the previous study [12], this case study produced approximately 40% higher estimates about SDW availability when forest resource and road network data from Sweden were included. It is important to take into account also transport possibilities from neighboring countries, at least when there are no obstacles hindering transportation over the border. In transportation between Finland and Sweden such obstacles do not exist, regardless of the fact that the currency exchange rate may cause some periodic changes in supply chains due to varying paying capacity for foreign feedstock.

In spite of varying data quality, OSM is a useful dataset for border-crossing analyses due to its global coverage. Especially in Central Europe, where supply areas may extend to several countries, demand for such analyses with international extent will most probably increase in the future as the number of large-scale biomass plants and refineries is expected to increase. Accordingly, such analyses are needed if the GHG emissions deriving from biomass supply are to be evaluated case-specifically instead of using general default values [12].

4 REFERENCES

[1] O.-J. Korpinen, E. Jäppinen & T. Ranta, A Geographical-origin-destination model designed for cost-calculations of multimodal forest fuel transportation, Journal of Geographic Information Systems, Vol. 5 (2013), No.1.

[2] E. Jäppinen, O.-J. Korpinen & T. Ranta, The Effects of Local Biomass Availability and Possibilities for Truck and Train Transportation on the Greenhouse Gas Emissions of a Small-Diameter Energy Wood Supply Chain, BioEnergy Research, Vol. 6 (2013), pag. 166-177.

[3] H. Koski, Does marginal cost pricing of public sector information spur firm growth? The Research Institute of The Finnish Economy, (2011), Discussion paper 1260.

[4] Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). http://eur-

lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:01:EN:HTML

[5] OpenStreetMap. Description. http://wiki.openstreetmap.org/wiki/Press_Kit

[6] Government Forestry and Woodlands Policy Statement, January 2013, http://www.defra.gov.uk/publications/2013/01/31/pb13871-forestry-policy-statement/

[7] Forestry Commission, National Forest Inventory outputs. http://www.forestry.gov.uk/website/forestry.nsf/byunique/INFD-8EYJWF

[8] Skog og landskap, Kilden - til arealinformasjon. http://www.skogoglandskap.no/kart/kilden

[9] EuroGeographics, Administrative units and statistical units. http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/administrative_units_statistical_units_1

[10] European Environment Agency, CORINE Land Cover, Description. http://www.eea.europa.eu/publications/COR0-landcover

[11] Metsäliitto (2011) Press Release: “Joint biodiesel project between Metsäliitto and Vapo to be possibly located in Ajos in Kemi, Finland”, 27.7.2011. https://newsclient.omxgroup.com/cdsPublic/viewDisclosure.action?disclosureId=463375&lang=en

[12] E. Jäppinen, O.-J. Korpinen & T. Ranta, GHG emissions of forest-biomass supply chains to commercial-scale liquid-biofuel production plants in Finland, GCB Bioenergy, (2013).

[13] Nordfjell, T., Nilsson, P., Henningsson, M. & Wästerlund, I. 2008. Unutilized biomass resources in Swedish young dense forests. In: Vinterbäck, J. (Ed) Proceedings: World Bioenergy 2008. pp 323-325.

[14] National Land Survey of Finland. The Topographic database. Description. http://www.maanmittauslaitos.fi/en/digituotteet/topographic-database

[15] Lantmäteriet. GSD - Sverigekartor, vektor. Description. http://www.lantmateriet.se/Kartor-och-geografisk-information/Kartor/Sverigekartor/GSD-Sverigekartor-vektor/Produktoversikt/

[16] Ranta. T. (2002) Logging residues from regeneration fellings - a GIS-based availability and supply cost analysis Finland. Acta Universitatis Lappeenrantaensis 128. 180 p. http://urn.fi/URN:ISBN:978-952-214-871-1

[17] Nationell vägdatabas, NVDB. Description. http://www.nvdb.se/

RFID-TECHNOLOGY DEMONSTRATION FOR INTERCHANGEABLE CONTAINER LOGISTICS

T. Ranta, J. Föhr, K. Karttunen, A. Knutas*
Lappeenranta University of Technology, Sammonkatu 12, 50130 Mikkeli, Finland
**Corresponding author: Tel: +358 408644994, Email: tapio.ranta@lut.fi*

Abstract

RIFD-technology (Radio Frequency Identification) is widely used in industry but has hardly any applications for energy biomass logistics. Interchangeable container logistics offers interesting target for such an application. RFID-system consists of tags, reader, antenna and electronic control system. RIFD-technology enables online tracking of biomass load information, keeping transaction logs and locating the load during the reading actions.

The aim of this demonstration study was to build a real-time web-based tracking system which use RFID to manage energy biomass logistics. By means of this system (RfIDER – Container Logistics System) it was possible to follow containers moving in the supply chain via internet-portal where all tracking data was stored in the virtual cloud server. Both smart phones with NFC-features (Near Field Communications) and gate readers equipped with a wireless internet connection were used for data transfer into RfIDER-system. During the demonstration study the functionality of this system was evaluated and further developed. Demonstration was executed by using trucks carrying both composite and metal interchangeable containers mounted with RFID-tags. Normally one truckload consisted of three containers. Also productivity of all work phases in the transportation chain was examined and the readability of RFID-tags was evaluated.

Demonstration study pointed out that the RfIDER-system made it possible to follow containers as real-time basis through the supply chain and both put and read information reliably of the single container, like the owner, origin, destination, content and quality of biomass. Containers were also located by giving a geographical identity at the same time when data was read. The readability of RFID-tags was better with composite than metal containers. Data gathering made it possible to compile useful statistics afterwards.

Potential benefits of the demonstrated system are real-time and accuracy of the gathered data and possibility to allocate and classify it according to the customer needs. Possible logistical advantages are better efficiencies of unloading operations at the energy plant by using the existing information stored at the system.

STUMP HARVESTING BIOMASS ESTIMATES ON 5 CONIFER TRIAL SITES IN IRELAND

Horgan B. Kent, T. & Coates, E

Ireland's demand for wood based biomass is increasing due to the implementation of the European Parliament Directive 2009/28/EC. It is estimated that there will be a shortfall of supply by the year 2020 of approximately 1.6 million cubic metres if only currently employed wood supply chains are used. Stump harvesting may be able supply biomass to contribute to this requirement, but at present no stump harvesting system is operating in Ireland. Before the adoption of such system, an evaluation of the biomass recoverable in Irish conditions is needed. This study evaluates the stump biomass harvested from five trial sites in Ireland during a collaborative trial between Waterford Institute of Technology (a university level institute in Ireland) and Coillte (the Irish State forestry company). The evaluation took place on two levels: i) the total biomass recovered on each site, ii) a relationship between stump size (variable of stump diameter) and dry matter. The trial took place on five sites: two peat soil, and three mineral soil conditions. All sites were conifer clearfells. In total, 4.83 hectares productive area was harvested. During harvesting, 90 stumps were selected, their diameter recorded, and their weight recorded individually. After weighing, each stump was cleaned thoroughly with a power washer to remove soil. After washing, the stumps were allowed to dry and then were reweighed. Moisture content samples were also taken from each of these stumps. This data allowed for the development of a mathematical stump diameter / dry matter relationship.

Currently the remaining stumps on each site are being forwarded to the roadside, where they will be transported to the end user (Medite, an MDF manufacturer in the south east of Ireland). All the material harvested is being recorded on a weighbridge, and moisture content samples taken.

Once complete, the study will report on the total biomass recovered from each site, the moisture content and its variation, and the piece size as explained by the covariate of stump diameter.

BIOMASS COMBUSTION AND POWER

INTERNATIONAL PELLET STANDARDS FOR INDUSTRIAL USE

Eija Alakangas, principal scientist, convenor of WG 2 of CEN/TC335 and ISO/TC238
VTT Technical Research Centre of Finland
P.O. Box 1603, FI-40101 Jyväskylä, Finland
e-mail: eija.alakangas@vtt.fi

ABSTRACT: ISO is currently preparing almost 60 standards for solid biofuels. ISO standards will supersede EN-standards in Europe. Pellet standards under development are: ISO 17225-1 General requirements, ISO 17225–2 Graded pellets and ISO 17225-6 Non-woody graded pellets. ISO 17225-2 includes also quality table for industrial pellets. Values for these standards have been agreed, and they will be published in 2014. ISO 17225-1 consist classification of raw material, which is based on their origin and source. ISO 17225-1 specifies woody biomass, herbaceous biomass, fruit biomass, aquatic biomass and blends and mixtures. Chemically treated material e.g. glued material shall not include halogenated organic compounds or heavy metals at levels higher than those in typical virgin material values. ISO 17225-1 includes also quality tables for thermally treated biomass (e.g. torrefied biomass).

Keywords: standards, wood pellet, industrial use, agropellet.

1 INTRODUCTION

The European Commission gave in year 2000 the mandate to the European Committee for Standardization (CEN) under technical committee CEN/TC335 to prepare standards for solid biofuels. In total 38 standards for terminology, fuel specification and classes, quality assurance, sampling and sample preparation, analysis physical and mechanical, and chemical properties were published. The two most important standard being developed deal with classification and specification (EN 14961) and quality assurance for solid biofuels (EN 15234). Both these standards are published as multipart standards [1].

The International Organization for Standardization (ISO) is currently preparing almost 60 standards for solid biofuels. For fuel specification and classes standard development time is 24 months starting from the time, work item proposal has been accepted. Pellet standards under development are ISO 17225-1 [3], ISO 17225–2 [4] Graded pellets (includes tables for residential and commercial use and industrial use) and ISO 17225-6 [5] Non-woody graded pellets. Commercial use means facility that utilise solid biofuel burning appliances or equipment that have the similar fuel requirements as residential appliances. Commercial applications should not be confused with industrial applications, which can utilise a much wider array of materials and have vastly different fuel requirements.

Table 1 shows the different development phases. Pellet standards ISO 17225-1, 2 and 6 are now in final draft international standard phase (FDIS) and all values have been accepted in May 2013. A standard for thermally treated densified biomass is under preparation phase. It has been discussed in March 2013 and there is support to start also preparation of this standard. New work item proposal will be made by Austria in June-July 2013. Parts 1 – 7 will be sent for final voting in summer 2013 and after 2 months balloting they will be publishing phase.

ISO/TC 238 and CEN/TC335 have decided to apply Vienna agreement (Fig. 1), which means that European standards will supersede by new ISO standards in European countries and will be published as ISO EN -standards. Other nations will make their national decisions.

Table 1. Development phase of international standards

Activity	**Action by**	**Time line**	**Status**
Proposal stage – New work item proposal (NWIP)	P-member of ISO/TC	3 months or at the TC meeting	Done for parts 1–7 Under discussion for thermally threated densified biomass
Preparatory stage – Working drafts (ISO/WD)			
Committee stage- Committee drafts (ISO/CD) ISO/CD ballots (comments to CD)	ISO/TC 238 Member bodies	12 months 3 months	Done for parts 1–7
Enquiry stage - Enquiry draft (ISO/DIS)			
Availability of DIS Ballot on ISO/DIS	ISO/TC 238 Member bodies	24 months 5 months	Done for parts 1–7
Approval stage – Final draft international standard (ISO/FDIS)			
Availability of FDIS Ballot on ISO/FDIS (only editorial comments allowed)	ISO/TC 238 Member bodies	32 months 2 months	Parts 1- 7 has been sent for voting in May 2013 July-August 2013
Publication stage – International standard (ISO)			
Distribution of ISO	ISO Central Secretariat	2 months after close of ballot	Parts 1-7 will be published in early 2014

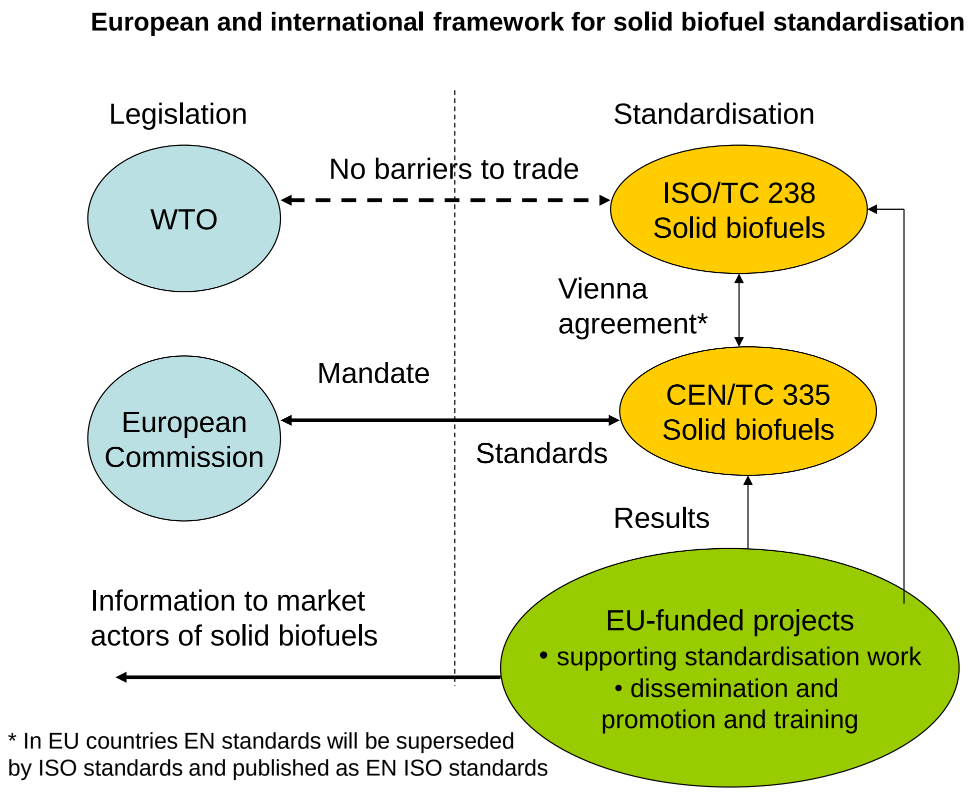


Figure 1: Applying Vienna agreement in solid biofuel standard development [1]

2 GENERAL REQUIREMENTS – ISO 17225-1 [3]

2.1 Classification of raw material

ISO 17225-1 [3] also includes the raw material classification of solid biofuels, which is based on their origin and source. Stating origin and source is normative (mandatory) for all biomass fuels. The fuel production chain of fuels shall be unambiguously traceable back over the whole chain.

ISO 17225-1 includes the following raw materials:

1. Woody biomass,
2. Herbaceous biomass,
3. Fruit biomass and
4. Aquatic biomass and
5. Blends and mixtures.

Chemically treated material e.g. glued, lacquered, painted wood shall not include halogenated organic compounds or heavy metals at levels higher than those in typical virgin material values or higher than typical values of the country of origin [2].

2.2 Biomass pellets in ISO 17225-1 standard

Biomass pellets are specified according to the Table 4 in ISO 17225-1 standard. This standard includes biopellets made from different kind kind of biomass raw materials. Property classes are not bind together so each property class can be selected separately. Normative (mandatory) property classes for pellet are dimensions (D, diameter and L, length), moisture (M on wet basis, w-%), ash (A, on dry basis w-% with pre-ashing temperature 550^{o}C), mechanical durability (DU, w-% pellets after drum testing), amount of fines (< 3.15 mm), bulk density (BD) and net calorific value as received (Q). If raw material includes chemically treated biomass, then also nitrogen (N), sulphur (S) and chlorine content (Cl) has to be stated. Ash behavior is informative (voluntary). It is recommended to state all characteristic temperatures (shrinkage starting temperature (SST), deformation temperature (DT), hemisphere temperature (HT) and flow temperature (FT)) in oxidizing conditions.

It also has additional properties like fixed carbon (C) and volatile matter (VM), which are specified only for thermally treated biomass (e.g. torrefied pellets). Fixed carbon (%) is calculated by the following:

100– moisture (w-%) + ash (w-%) + volatile matter (w-%).

All percentages are on the same moisture basis. Thermally treated biomass pellets are also taken into account in bulk density classes and there are classes up to 750 kg/m^3.

3 GRADED WOOD PELLETS – ISO 17225-2 [4]

Graded wood pellets include tables for non-industrial use and industrial use (Table 2). Industrial wood pellets fuel specification is based on the proposal for fuel of the Industrial Wood Pellets Byers Group (IWPB). Biopellets in ISO 17225-1 [3] and industrial wood pellets in ISO 17225-2 [4] also include property classes for the particle size distribution for disintegrated pellets.

Wood pellets for non-industrial use will also be specified according to ISO 17225-2 (Table 1 in the standard, [3]). Property class A1 for wood pellets represents virgin woods and chemically untreated wood residues low in ash and nitrogen content. Fuels with slightly higher ash content and nitrogen content fall within grade A2. In property class B also chemically treated industrial wood by-products and residues and chemically untreated used wood is allowed, but they have same very strict threshold values for heavy metals. To protect small-scale consumer some heavy metals (Cl, As, Cd, Cr, Cu, Pb, Hg, Ni and Zn) are normative for wood pellets for non-industrial use. Torrefied pellets are excluded from the scope of this standard, they will be included in ISO 17225-1 [3] and there is also a proposal to produce also product standard for Graded thermally treated densified biomass.

Table 2. Specification of graded wood pellets for industrial use (Final draft international standard – ISO 17225-2)

	Property class, Analysis method	**Unit**	**I1**	**I2**	**I3**
Normative	**Origin and source**, ISO 17225-1		1.1 Forest, plantation and other virgin wood 1.2.1 Chemically untreated wood residues [a]	1.1 Forest, plantation and other virgin wood 1.2.1 Chemically untreated wood residues [a]	1.1 Forest, plantation and other virgin wood 1.2 By-products and residues from wood processing industry 1.3.1 Chemically untreated used wood
	Diameter, D [b] and **Length L** [c], ISO 17829	mm	D06, 6 ± 1; 3,15 < L ≤ 40 D08, 8 ± 1; 3,15 < L ≤ 40	D06, 6 ± 1; 3,15 < L ≤ 40 D08, 8 ± 1; 3,15 < L ≤ 40 D10, 10 ± 1; 3,15 < L ≤ 40	D06, 6 ± 1; 3,15 < L ≤ 40 D08, 8 ± 1; 3,15 < L ≤ 40 D10, 10 ± 1; 3,15 < L ≤ 40 D12, 12 ± 1; 3,15 < L ≤ 40
	Moisture, M, ISO 18134-1, ISO 18134-2	w-% as received, wet basis	M10 ≤ 10	M10 ≤ 10	M10 ≤ 10
	Ash, A, ISO 18122	w-% dry	A1.0 ≤ 1,0	A1.5 ≤ 1,5	A3.0 ≤ 3,0
	Mechanical durability, DU, ISO 17831-1	w-% as received	97,5 ≤ DU ≤ 99,0	97,5 ≤ DU ≤ 99,0	96,5 ≤ DU ≤ 99,0
	Fines, F [d], ISO 18846	w-% as received	F4.0 ≤ 4,0	F5.0 ≤ 5,0	F6.0 ≤ 6,0
	Additives [e]	w-% as received	< 3 Type and amount to be stated	< 3 Type and amount to be stated	< 3 Type and amount to be stated
	Net calorific value, Q, ISO 18125	MJ/kg as received	Q16.5 ≥ 16,5	Q16.5 ≥ 16,5	Q16.5 ≥ 16,5
	Bulk density, BD [f], ISO 17828	kg/m^3	BD600 ≥ 600	BD600 ≥ 600	BD600 ≥ 600
	Nitrogen, N, ISO 16948	w-% dry	N0.3 ≤ 0,3	N0.3 ≤ 0,3	N0.6 ≤ 0,6
	Particle size distribution of disintegrated pellets, ISO 17830	w-% dry	≥ 99% (< 3,15 mm) ≥ 95% (< 2,0 mm) ≥ 60% (< 1,0 mm)	≥ 98% (< 3,15 mm) ≥ 90% (< 2,0 mm) ≥ 50% (< 1,0 mm)	≥ 97% (< 3,15 mm) ≥ 85% (< 2,0 mm) ≥ 40% (< 1,0 mm)
	Sulphur , S, ISO 16994	w-% dry	S0.05 ≤ 0,05	S0.05 ≤ 0,05	S0.05 ≤ 0,05
	Chlorine, Cl, ISO 16994	w-% dry	Cl0.03 ≤ 0,03	Cl0.05 ≤ 0,05	Cl0.1 ≤ 0,1
	Arsenic, As, ISO 16968	mg/kg dry	≤ 2	≤ 2	≤ 2
	Cadmium, Cd, ISO 16968	mg/kg dry	≤ 1,0	≤ 1,0	≤ 1,0
	Chromium, Cr, ISO 16968	mg/kg dry	≤ 15	≤ 15	≤ 15
	Copper, Cu, ISO 16968	mg/kg dry	≤ 20	≤ 20	≤ 20
	Lead, Pb, ISO 16968	mg/kg dry	≤ 20	≤ 20	≤ 20
	Mercury, Hg, ISO 16968	mg/kg dry	≤ 0,1	≤ 0,1	≤ 0,1
	Zinc, Zn, ISO 16968	mg/kg dry	≤ 200	≤ 200	≤ 200
	Informative **Ash melting behaviour**, CEN/TS 15370-1	^oC	should be stated	should be stated	should be stated

[a] Negligible levels of glue, grease and other timber production additives used in sawmills during production of timber and timber product from virgin wood are acceptable if all chemical parameters of the pellets are clearly within the limits and/or concentrations are too small to be concerned with.
[b] Selected size D06, D08, D10 or D12 of pellets to be stated.
[c] Amount of pellets longer than 40 mm can be 1 w-%. Maximum length shall be ≤ 45 mm. Pellets are longer than 3,15 mm, if they stay on a round hole-sieve of 3,15 mm. Amount of pellets shorter than 10 mm, w-% recommended to be stated.
[d] At factory gate in bulk transport (at the time of loading) and in small (up to 20 kg) and large sacks (at time of packing or when delivering to end-user).
[e] Type of additives to aid production, delivery or combustion (e.g. pressing aids, slagging inhibitors or any other additives like starch, corn flour, potato flour, vegetable oil, lignin.
[f] Maximum bulk density is 750 kg/m^3.
[g] It is recommended that all characteristic temperatures (shrinkage starting temperature (SST), deformation temperature (DT), hemisphere temperature (HT) and flow temperature (FT) in oxidizing conditions should be stated.

4 GRADED NON-WOODY PELLETS – ISO 17225-6 [5]

Non-woody pellets include pellets made from blends and mixtures including mainly herbaceous, fruit biomass or aquatic biomass. Blends and mixtures can include also woody biomass. ISO 17225-6 [5] is for non-woody pellets and there are two classification tables:

- A and B class pellets produced from herbaceous and fruit biomass and blends and mixtures and
- Table for straw, miscanthus and reed canary grass pellets.

Non-woody pellets have high ash, chlorine, nitrogen and sulphur content and major element contents, so non-woody pellets are recommended to be used in appliances, which are specially designed or adjusted for this kind of pellet.

When using non-woody materials for combustion special attention should be paid to the risk of corrosion in small and medium scale boilers and flue gas systems. Herbaceous or fruit biomass may influence the fuel ash composition differently depending on growth and soil conditions. The content of chlorine, phosphate and potassium in the material may form chlorides and phosphates and other chemical compounds resulting in high hydrochloric emissions and chemically active ash with low melting temperature causing corrosion.

In general non-woody biomass materials have higher content of ash forming elements and produces ashes with lower melting temperature compared to most woody biomass. This may result in fouling, slagging and corrosion inside boilers. These problems are especially related to materials that contain high content of potassium (K) and silicate (Si) and low content of calcium (Ca).

5 STANDARD DEVELOPMENT AND FUTURE

The SolidStandards project has collected feedback of European standards for solid biofuels though internet and in the 35 training events organized by the project partners. This work has support also drafting the ISO standards, because new ISO standards are mainly based on existing EN-standards.

Also different international fuel analysis laboratories have submitted measured data of wood and agropellet properties for ISO/TC 238 working group 2, which is responsible for drafting the pellet standards. Finland is holding the secretariat for this working group. Data has been used, when discussing of threshold values for these pellets. In last ISO/TC 238 meeting of working group 2, which was held in Bangkok in March 2013, values of wood pellets for residential and commercial industrial use has been changed for ash content and sulphur content based on these studies.

Fuel specification standards (ISO 17225-serie) will be published in year 2014.

6 REFERENCES

[1] Alakangas, E. Towards international standards – industrial wood pellet standards under development, 21st European Biomass Conference and Exhibition 2013, Copenhagen, 3 – 6 June 2013, paper, 3 p.

[2] Alakangas, E. & Groot, M. Implementation of quality standards - General part, Training material, SolidStandards IEE project. 2012. p. 34

FIRST RESULTS OF THE SECTOR-PROJECT: PRODUCTION OF SOLID SUSTAINABLE ENERGY CARRIERS FROM BIOMASS BY MEANS OF TORREFACTION

K. Schaubach[1], J. Kiel[2], M. Carbo[2], M. Wojcik[3]
1. DBFZ Deutsches Biomasseforschungszentrum gGmbH, Torgauer Straße 116, D-04347 Leipzig, Germany
2. ECN Energy Research Centre of the Netherlands. 1755 ZG Petten, The Netherlands
3. OFI Austrian Research Institute for Chemistry and Technology, 1110 Vienna, Austria
info@sector-project.eu

ABSTRACT: Within the European (FP7) project SECTOR, the further development of torrefaction-based technologies for the production of solid bioenergy carriers up to pilot-plant scale and beyond is assessed. The project consortium of more than 20 partners from industry and science support the market introduction of torrefaction-based bioenergy carriers as a commodity solid biofuel. The SECTOR project, which started in January 2012, is expected to shorten the time-to-market of torrefaction technology and to promote market introduction within stringent sustainability boundary conditions. In the torrefaction process biomass is heated up in the absence of oxygen to a temperature of at least 250°C. By combining torrefaction with pelletisation or briquetting, biomass materials can be converted into a high-energy-density bioenergy carrier with improved behaviour in transport, handling and storage. Torrefaction also creates superior properties for biomass in many major end-use applications. The process has the potential to provide a significant contribution to an enlarged raw material portfolio for sustainable biomass fuel production inside Europe by including both agricultural and forestry biomass (residues).
The paper briefly introduces the project, its objectives and the results obtained within the first project phase. As the project is organised along the value chain, the shown results comprise of the assessment of biomass availability, production of torrefied biomass batches, subsequent densification, characterisation and Round Robin testing of characterisation methods as well as sustainability assessment along the value chain.

KEYWORDS: torrefaction; solid biofuel; sustainability

1 INTRODUCTION

The torrefaction of biomass materials is considered to be a very promising technology for the promotion of the large-scale implementation of bioenergy. By combining torrefaction with pelletisation or briquetting, biomass materials can be converted into a high-energy-density commodity solid fuel or bioenergy carrier with improved behaviour in (long-distance) transport, handling and storage and also with superior properties in many major end-use applications. Therefore, technology development is currently pushed with different research and demonstration projects in the European Union and North America (Figure 1). Especially the use of torrefied biomass for co-firing in coal power stations would significantly contribute to the fulfilment of the political targets – the provision of 20% of the primary energy consumption through renewable fuels until 2020 – without major technical adaptations. Besides the use of torrefied pellets in coal power stations, further market areas are currently evaluated.

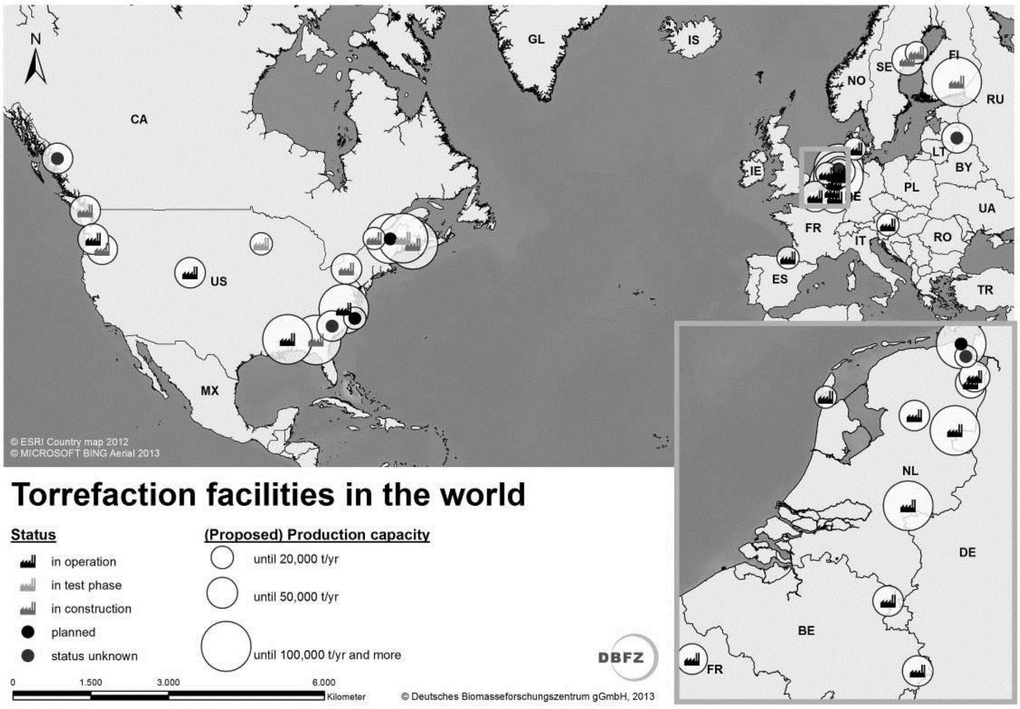


Figure 1: Torrefaction facilities in the world. Source: DBFZ

2 SECTOR OVERVIEW

SECTOR is a large-scale European project within the Seventh Framework Programme of the European Union. It started in January 2012 and will last 42 months. The consortium of more than 20 partners from industry (e.g. EoN, Vattenfall, RWE Innogy, Doosan Power Systems) and science (e.g. DBFZ, OFI, TFZ) covers nearly all aspects of the biomass value chain – from analysis of raw materials, production and storage of torrefied biomass up to logistics and end use (Figure 3).

The project is focused on the further development of torrefaction-based technologies for the production of solid bioenergy carriers up to pilot-plant scale and beyond, and on supporting the market introduction of torrefaction-based bioenergy carriers as a commodity renewable solid fuel.

In parallel to the development of torrefaction and densification technologies the consortium will work on the assessment of selected logistics aspects and the use of torrefied products in existing conversion options as well as fuel specification and testing methods. This is complemented by a full sustainability assessment of torrefaction-based biomass-to-end-use value chains. In this way, the SECTOR project is expected to shorten the time-to-market of torrefaction technology and to promote market introduction within stringent sustainability boundary conditions. The project is coordinated by DBFZ – Deutsches Biomasseforschungszentrum gGmbH.

3 TECHNOLOGY AND PROCESS

Torrefaction involves heating biomass in the absence of oxygen to a temperature of 250-320 °C. At these temperatures, a dry, torrefied product is obtained, which is stable, brittle and water resistant. This makes it much easier to grind than the parent biomass material and reduces biological degradation in storage.

Provided that the torrefaction process is conducted in an energy-efficient manner, i.e. with heat recovery and integration, overall biomass-to-torrefied-pellets energy efficiencies exceeding 90% (based on lower heating value) can be reached. Thus, the overall energy efficiency of torrefaction-based biomass supply chains is increased, simultaneously reducing the CO_2 footprint and costs. In addition to the possible reduction of CO_2 emissions, torrefaction can help to exploit the large potential of residues.

Worldwide there are different technology options for torrefaction which also influence the properties of the torrefied material. The different reactor types and technologies followed by European technology developers are shown in Table 1. Partners in the SECTOR project with pilot plants are ECN, BioEndev and CENER, the company Topell is involved with its demo scale plant.

Table 1: Reactor Technologies of different European companies or institutions for the production of torrefied biomass [1], adapted: SECTOR-Partners in bolt

Reactor Technology	**European Technology developers & suppliers**
Rotary Drum	CDS (UK), Torr-Coal (NL), **BioEndev (SE)**, ACB (AT), BIO3D (FR), Atmosclear (CH), **CENER (ES)**
Multiple hearth furnace	CMI-NESA (BE)
Screw reactor	BioLake (NL), FoxCoal (NL)
Torbed reactor	**Topell (NL)**
Moving bed reactor	**ECN (NL),** Thermya (FR), Bühler (CH)
Belt reactor	Stramproy Green (NL)
Fluidised bed reactor	**VTT (FI)**

4 CHANCES AND FIELDS OF APPLICATION

Torrefaction has the potential to provide a significant contribution to an enlarged raw material portfolio for biomass fuel production inside Europe by including both agricultural and forestry biomass. The main focus will be on residual materials. It may enable the opening of new feedstock sources worldwide and allow import into Europe in an economically and environmentally sustainable manner. For example, due to the high energy density of torrefied and densified materials, typically three to five times higher than the original biomass, the energy requirements for intercontinental transport can be limited to only a few per cent of the energy content of the bioenergy carrier. This is similar to the transport energy levels for coal, and due to the consistent quality of the torrefied product, it is possible that trading schemes similar to those for coal can be applied.

With respect to the end-use, torrefaction-based bioenergy carriers may form a good starting point for (thermo-chemical) biorefinery routes. Furthermore, the homogenous quality of the fuel that is aimed for and the advantageous product quality of torrefied biomass offers optimal conditions for the use for co-firing in coal-fired power stations in order to substitute fossil fuels (Figure 2). The brittle structure of the material breaking down easily makes it possible to grind the densified fuel in the existing mills of coal power plants. Furthermore, there are cost advantages for transport and storage due to the very low water content and the moderately hydrophobic properties of the torrefied material.

Figure 2: Comparison of the properties of torrefied material with wood pellets and coal. Source: ECN

	Wood pellets	Torrefied wood pellets	Coal
Moisture content (wt%)	7 – 10	1 – 5	10 – 15
Calorific value (LHV, MJ/kg) As received	15 – 17	18 – 24	23 – 28
Volatile matter (wt% db)	75 – 84	55 – 65	15 – 30
Fixed carbon (wt% db)	16 – 25	22 – 35	50 – 55
Bulk density (kg/l)	0.55 – 0.65	0.65 – 0.80	0.80 – 0.85
Vol. energy density (GJ/m^3)	8 – 11	12 – 19	18 – 24
Hygroscopic properties	Hydrophilic	(Moderately) Hydrophobic	Hydrophobic
Biological degradation	Fast	Slow	None
Milling requirements	Special	Standard – feedstock specific	Standard
Product consistency	High	High	High
Transport cost	Medium	Low	Low

Abbreviations:
db = dry basis
LHV =Lower Heating Value

5 FIRST PROJECT RESULTS

Within the first phase of the project, a market assessment for biomass feedstock has been prepared in order to identify the largest and most interesting biomass potentials [3]. Biomass potentials were divided into wood based fuels, agricultural residues and energy crops. The total wood energy potential in the EU-27 was identified to be 3,700 PJ/a with the largest potentials existing for stem wood and forest residues. The main potential for agricultural residues is seen for cereal straw residues (up to 980 PJ/a in EU-27 and up to 13,500 PJ/a globally). For energy crops such as Miscanthus, reed canary grass, short rotation coppice or bamboo only theoretical potentials are available which largely depend on diet scenarios and the respective available area for cultivation.

In the torrefaction and densification work packages, at first evaluation criteria and requirements on the feedstock were defined [2]. Several tonnes of torrefied biomass have been produced and densified (pelletised and briquetted) by the different suppliers. This material has been supplied to different project partners for testing of storage and handling as well as end-use in applications such as co-firing, co-gasification and small-scale combustion. First results were obtained in mass yield comparison tests by ECN for thermogravimetric analysis as well as in batch and pilot scale experiments for various feedstock. These results can be used to determine the extent of exothermic behaviour in commercial scale torrefaction plants and to determine the appropriate setpoints for the torrefaction process. Pilot scale production of torrefied material from straw was carried out by CENER in their cylindrical horizontal reactor with an agitator shaft. Densification experiments were carried out by DTI on laboratory scale with materials from different project partners. The respective results give an indication what equipment and parameters should be used for pelletisation.

An extensive Round Robin test with torrefied pellets has been carried out, which was aimed at validating standard test methods to specify characteristic fuel properties [5]. More than 40 international laboratories joined the Round Robin test. With respect to standardisation, the preparation of material safety data sheets for torrefied material has been pursued further.

The results of SECTOR were transferred to the ISO standardisation committee in Bangkok in March 2013 which resulted in the decision to prepare a new product standard (ISO 17225-X) for graded thermally treated densified biomass.

Finally, the work package on sustainability assessment has developed a methodology for the life-cycle-assessment and socio-economic assessment of the torrefaction-based value chains and for the environmental assessment in the form of case studies in specified focus regions such as Central Europe, Southern USA and Tanzania [4].

6 CONCLUSIONS

The torrefaction of lignocellulosic material offers optimal conditions for a better utilisation of the available biomass and can put residual biomass to a new use. Some of the torrefaction processes currently under development are close to market implementation. One of the challenges still is the continuous process control during torrefaction because during commercial operation the raw material will vary in respect to its properties (type of biomass, age, growing location etc.) During subsequent pelleting or briquetting of the dry, brittle material the optimal process conditions (pressure, temperature, size etc.) and the effective addition of a binder are still under research. Aimed for is the production of a solid fuel with a high energy and bulk density which will allow optimal conditions for transport, storage and use in different applications. Only after those technical and commercial challenges are solved and the production of a homogenous torrefied fuel is possible in continuous operation the transfer of the process technology from Pilot/Demo-Scale towards industrial scale will take place.

Thus, the European project SECTOR with its partners supports the product and market implementation of standardised torrefied fuel from biomass in Europe.

Figure 3: Partners of SECTOR project coordinated by DBFZ Deutsches Biomasseforschungszentrum gGmbH

More information can be found at www.sector-project.eu.

7 REFERENCES

[1] Kleinschmidt, C.P., Overview of international developments in torrefaction.

[2] Zwart, R. et al., Working paper on evaluation criteria and selection of feedstock. Deliverable No. D3.1 SECTOR, 2012

[3] Alakangas, E.. et al., Market assessment of biomass feedstock available for torrefaction. Deliverable No. D2.2, SECTOR, 2013

[4] Kranzl, L. et al., Description of the relevant biomass-to-end-use chains, including torrefied biofuels. Deliverable No. D9.1, SECTOR, 2012

[5] Wojcik, M. et al., Report Round Robin I – validation of "standard" test methods. Deliverable No. D8.1, SECTOR, 2013

(www.solidstandard.eu)

[3] ISO 17225-1, Solid biofuels – General requirements, Final Draft International standard, N161, May 2013.

[4] ISO 17225-2, Solid biofuels – Graded wood pellets, Final Draft International standard, N162, May 2013.

[5] ISO 17225-6, Solid biofuels – Graded non-woody pellets, Draft International standard, N166, May 2013.

6 ACKNOWLEDGEMENTS

The Author is grateful to the project partners of SolidStandards project and Working Group 2 of ISO/TC 228.

The SolidStandards project is co-funded by the European Union under the Intelligent Energy Europe Programme (Contract No. EIE/11/218).

The SolidStandards project addresses ongoing and recent developments related to solid biofuel quality and sustainability issues, in particular the development of related standards and certification systems. In the SolidStandards project, solid biofuel industry players will be informed and trained in the field of standards and certification and their feedback is collected and provided to the related standardization committees and policy makers.

The sole responsibility for the content of this paper lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the EACI nor the European Commission is responsible for any use that may be made of the information contained therein.

ZILKHA BLACK® PELLET HANDLING, STORAGE, AND GRINDING IN EXISTING COAL PLANTS

Larry Weick, VP Business Development, Zilkha Biomass Energy, Houston, Texas USA

Zilkha Black pellets are additive-free wood pellets that are hard, low dust, and waterproof. Black pellets are a drop-in replacement fuel for pulverized coal units, gasifiers, and other coal-capable power generating units worldwide. Black pellets have been successfully shipped in bulk and fired in full scale tests in Europe. By switching to Black pellets, utilities can generate renewable power from their existing coal plants with minimal new investment capital. Mechanics and key benefits of safe storage and handling, grinding, and combustion will be covered.

EXPERIENCE OF A BIG PELLET BOILER

Tero Joronen
Boilers and Combustion Manager
Metso - MW Power
Lentokentänkatu 11, P.O. Box 109, FIN-33101 Tampere, Finland
first.lastname@metso.com

ABSTRACT: The purpose of this paper is to introduce an application of pulverized wood pellet-firing in district heating. The application offers an alternative for fossil fuel based peak and backup heat generation and it can be utilized instead of the more commonly used oil- and gas-fired solutions. The starting, ramp up and shut down times are comparable to these traditional solutions. Wood pellets offer low CO2 alternative and additional fuel in the portfolio increases flexibility and offers cost saving in the fuel management. The Tampere case is especially interesting due to the large-scale utilization of pellets, and rapid load changes.
The Tampere case is a wood pellet-fired district heating plant for Tampereen Energiantuotanto Oy. The delivery comprised a full-scope turn-key boiler plant solution, including all the necessary equipment, and commissioning. The heating plant is used as a peak load and backup plant and it will replace some of the existing oil- and gas-fired capacity. Replacing old boilers with a modern pellet-fired boiler will significantly reduce the CO2 emissions resulting from the production of district heating. The plant's thermal input is 33 MW with pellets, and it started the heat production in the end of year 2012. The burner has a light oil firing possibility with 47 MW firing rate.

Pulverized fuel allows clean, energy-efficient and flexible heat generation during start-ups, and quick load changes during the production. The plants control capability fulfills the requirement of the district heating network of the Tampere. Flue gas emissions requirements are met; wood pellet is fired with low CO and NOx emission. The plant efficiency and the availability are high. Due to its beneficial properties, pulverized pellet combustion is an expanding technology in the field of biomass-based energy generation.

1 WOOD PELLET

Concern of the CO2 emission boosts renewable energy production. The biomass combustion offers an alternative that is totally independent of weather conditions at all hours. Pellet-firing offers a high energy density and tidy alternative to fossil fuels that can be utilized in urban surroundings. Pellets are mainly utilized in small-scale central heating application, co-fired in pulverized coal combustion or special pellet-fired burners (Obernberger & Thek, 2010). The pellet-fired burner application offers flexibility and capacity comparable to the oil and gas fired applications.

Figure 1. The wood pellet is a high-quality fuel with a constant quality and properties.

Pellets are high-quality biomass fuel that provides a consistent alternative to conventional fuels like coal, oil and natural gas. Pellets are a good alternative as they are low in moisture, high in energy density and homogenous in size and shape (Obernberger & Thek, 2010). The characteristics of wood pellets compared to wood chips are significantly better; higher calorific power, lower moisture content, apparent density and ash content (see Table 3.) The energetic content per unit volume is about four times better for pellet compared to wood chip. This makes the application of wood pellets feasible also in urban environments as high amounts of thermal energy can be stored in relatively small volumes compared to wood chips. The pellets are delivered by trucks that can offload pneumatically to enclosed silo, thus there are no dust emissions to the environment from the fuel handling.

Table 1. Main characteristics of wood pellets and wood chips (Giacomo & Taglieri, 2009)

	Wood pellets	*Wood chips*
Calorific power	*17.0 GJ/t* *4.7 kWh/kg* *3080 kWh/m³*	*13.4 GJ/t* *3.7 kWH/kg* *750 kWh/m³*
Water	*8%*	*25% (Finland 45 %)*
Apparent density	*650 kg/m³*	*200 kg/m³*
Ashes content	*0.5%*	*1%*

The pellets are available globally for a competitive price and simple and sufficient fuel logistics. For instance, the English markets have developed to enable the larger-scale utilization of wood pellets and provide increasing potential for greenhouse gas reduction (Hansen;Jein;Hayes;& Betaman, 2009). In addition, on the Mediterranean region, Giacomo and Taglieri found the potential of woody pellets to be significant and the applications would be economically and environmentally feasible (Giacomo & Taglieri, 2009).

2 PELLET-FIRED BURNER APPLICATIONS

The advantages of entrained pulverized pellet-fired combustion are the availability of low NOx combustion, good load control and the possibility of fast alternation of load. The disadvantages are the relatively higher variable and fixed costs due to limited particle size and the requirement of a start-up burner (Swithenbank; Chen;Zhang;& Sharifi, 2011). In the normal implementation the pellet firing is integrated into a multi-fuel burner that starts as an oil-fired burner and after heating up converts to pellet firing (Forsberg, 2012). The fuel flexibility decreases the dependence of the single fuel.

One major reason to invest in a pellet-fired heating plant is to reduce the utilization of fossil fuels in peak, back-up and industrial boiler plants. The retrofitting existing oil & gas application to the multi-fuel solution offers a feasible potential. The pellet firing has a low environmental impact, as the pellet-fired plants are almost CO_2 emission free. Naturally some CO_2 production results from the harvesting, production and transport of the pellets, but these emissions are far lower compared to oil combustion.

The possibility to implement fast load changes and start-ups makes it possible to apply pellet-fired boilers almost as flexibly as oil- or gas-fired boilers. Some limitations come with the lower energy density compared to oil. Larger storage volumes are required and stocks need to be refilled quite frequently. However, no dust or odor emissions emanate from the plant as the fuel handling is completely closed system.

The pellet-fired burner is very reliable, the final pellet feeding is achieved by using pressurized air and it is practically as reliable as the applications in pulverized coal combustion. The operations of the burner are fully comparable to those of oil burners. For instance, the ignition of the burner is fully automatic, as well the operation of the whole plant. The plant is remotely controlled and is unmanned.

The utilization of pellets is feasible if the price of alternative peak load fuel (typically oil or natural gas) is high enough and the gained CO_2 reduction has additional value though CO_2 trading. The price level of the pellet, due to higher taxation of fossil fuels, for instance, in Sweden the cost per MWh being approximately close to 40 % of that of oil (Lehtinen, Marjaana, 2012). The pellet market has extra production capacity available.

3 THE TAMPERE HEAT PLANT

Metso owned MW Power has delivered pellet-fired burners for environmentally friendly applications for several years already. A green solution was developed based on market demand. Renewable energy from biomass is obviously the way of the future. Pellet firing is somewhere between oil and wet biofuel with regards to complexity, cost, fuel variation, and other factors. The delivery includes complete process equipment with all the major components, including the fuel handling, fuel mill, burner, boiler, exhaust filters and control system.

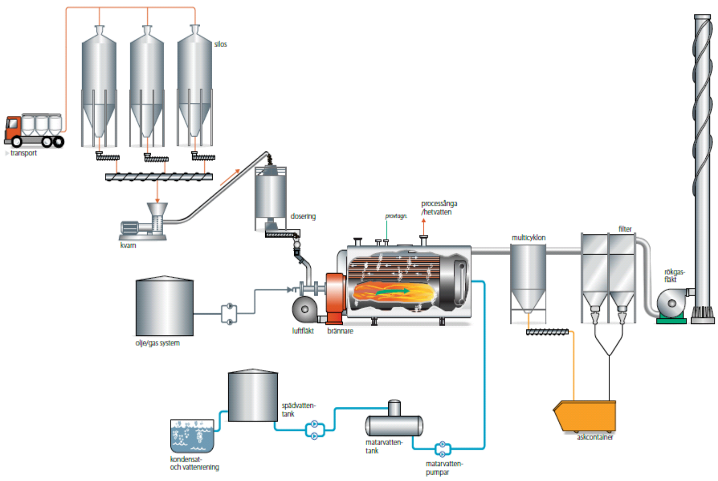


Figure 1. Basic process arrangement in a pellet-fired heating plant

In the solution, the pellet fuel is stored in separated storage silos. The pellets are pulverized in a separate grinding mill that blows the pulverized pellets into a smaller dust silo. From the dust silo the wood dust is metered by a dosing device into a pressurized air feeding line (Figure). Pulverized and consistent fuel quality allows complete combustion with limited CO emissions. The pellet-fired burner has a turning rate of approximately 1:4. The high boiler efficiency is possible as the water content of the fuel is low. The low variation of the fuel characteristics makes it possible to design the burner for flexible heat generation. This makes it possible to control the boiler load in a wide range at 10% per min, thus the time from the minimum to the maximum load is only 7.5 minutes. The load change rate is in many cases network-limited as the temperature and flow can't be changed as fast as the rate of change for the burner and the boiler.

The boiler and flue gas cleaning is specially designed for wood dust combustion. Furnace heat loading and arrangement of heat exchange surfaces are take care of combustion circumstances to ensure high availability, stable combustion, low emission, and fouling in the boiler. A special combustion model was developed to simulate the combustion and boiler performance. The technology partner in the combustion technology is World Thermal Service Ab (WTS) from Sweden. WTS has proven reliable and solid performance in combustion power and flue gas emission requirements. Applied powder burners are available for a power range of 2–50 MWth. The particle size of all of the pellet dust must be below 1 mm, and 70% below 0.5 mm, and moisture content below 10–12 %. The reference lists the flue gas emission ranges as follows; NOx emissions are 100–200 mg/Nm³ and for CO in the range of 0–50 mg/Nm³ (Forsberg, 2012).

Whenever handling dry pulverized wood, there is possibility certain fire risk. This issue is taken carefully into consideration within the concept. There are several special combustion detectors situated in critical locations within the pulverized pellet supply system. The detectors automatically activate the water mist spray to limit the temperature to prevent a fire from developing. An effective means of protection is to neutralize the small amounts of energy (ignition sources) before they manage to ignite the fine particles (See for instance; Firefly, www.firefly.se, 2012).

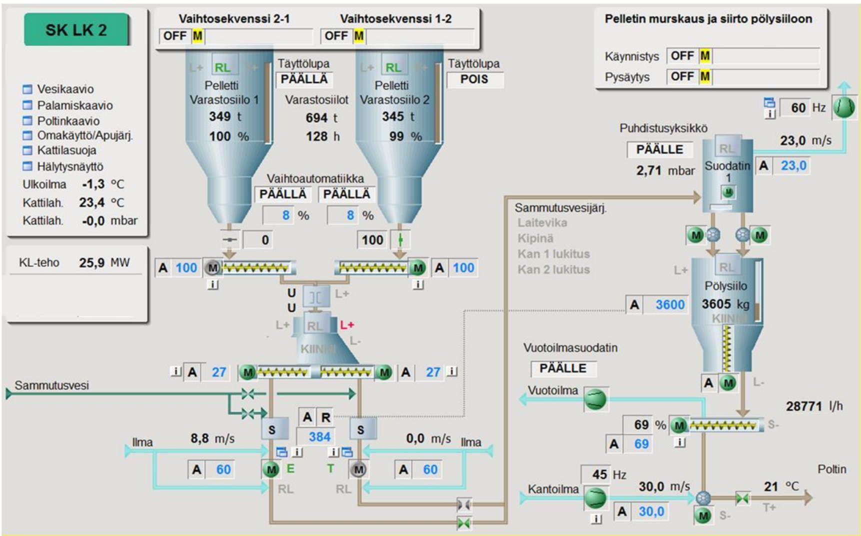
The Tampere plant is a wood pellet-fired district heating plant to Tampereen Energiantuotanto Oy. The company is a subsidiary of Tampere Power Utility (Tampereen Sähkölaitos, TKS) and responsible for the group's electricity and district heating production and maintenance of the systems. The pellet-fired plant is a good addition to their long-term heating plant palette. Increasing the proportion of renewable energy sources is part of their strategy. For example, in recent years, they have continuously increased the use of biomass in their Naistenlahti 2 BFB fired power plant unit (Lehtinen, Marjaana, 2012). The new heating plant will utilize MW Power's pellet firing solution, district heating and plant delivery expertise (See Figure).

4 ADVANTAGES FOR DISTRICT HEAT WITH PELLET FIRED PLANT

District heat networks are built in city areas where heat demand is dense enough for economical business. In smaller networks, heat production units are used due to smaller investment cost. In bigger networks, combined heat and power (CHP) production units with high energy efficiency are economical. In this case, the heat plants are applied as peak load capacity and reserve. Traditionally in Finland heat plants are oil, gas, wood chips or peat fired. Nowadays wood pellets are also available globally and offer a feasible alternative.

The economical trends affect the heat plant market, for instance, Europe is now in recession. In the recession, extra electricity production capacity is available while the use of it decreases bringing the price of it down. The heat production becomes more feasible as the production of the electricity is not as profitable. When times are tight, application of local work and materials decreases the variable cost. There are also affect to the local economy, money rotates in homeland, bringing jobs and welfare.
In the city of Tampere, the district heat is gas-based. The Naistenlahti CHP plant uses quite a lot of woodchips and peat. Heat is product mainly on gas turbines and in the heat recovery boilers connected to them. In general, the price of gas follows the oil price and keeps on rising. In Finland, the tax of the heat production depends on applied fuels. Due to rising gas price and tax and decreasing electricity price often running the gas-fired CHP plants is not profitable. This is dependent of the heat load, and it might be high, and this makes the pellet-fired heat only plant easily feasible.

Applying wood pellet increases the use of sustainable energy and helps fulfilling the renewable energy requirements. Thus wood pellets have no extra tax on heat production. The total price of pellet-based heat is lower than gas-based, but higher than wood chip-based. When the annual operating hours of the heat plant are limited the investment on more expensive woodchip boiler is not feasible. Pellet is an economical alternative when annual operating hours are between 500 and 3000. The lower limit comes from the comparison to the heavy oil firing, and above the higher limit wood chip-fired boiler becomes cost-effective. Having several optional fuels in the production portfolio increases the economical flexibility when the fuel prices go up and down.



Picture 1. A screen shot of the plant automation, flue management

The delivery comprised a full-scope turn-key boiler plant solution, including all the necessary equipment, tailored Metso DNA automation system, fully automatic control application, and commissioning. The heating plant is used as a peak load and backup plant and it will replace some of the existing oil- and gas-fired capacity. Replacing old boilers with a modern pellet-fired boiler will significantly reduce the $CO2$ emissions resulting from the production of district heating. The boilers design values are listed in Table 2.

Picture 2. The view of the plant from the gate

Table 2. The technical data of the Tampere pellet-fired district heating plant

Thermal output	33 MWth (pellet) and 47 MW (light oil)
Annual production	28,500 MWh (estimation)
Start-up of heat production	By the end of 2012
Load control	Modulating operation Peak load and back up boiler plant Turn down ratio 1:4 Load change rate 10%/min for the burner and the boiler
Fuel storages	Pellet silos 2x500 m³ Pellet dust 50 m³
Boiler efficiency	over 92%
Flue gas cleaning	Electrostatic precipitator

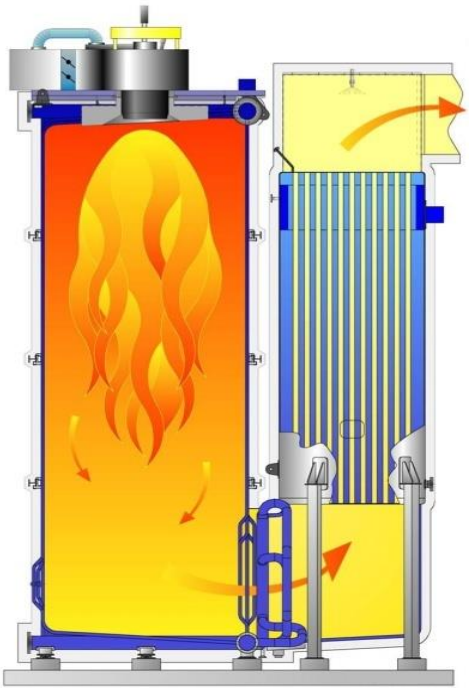


Figure 2. The side view of the Tampere pellet-fired boiler

5 OPERATIONAL EXPERIENCE

The plant has been in operation since the first pellet fire 16th December 2012. The plant has been over taken after the tuning and testing period. The flue gas emissions are meeting the emission limits. The thermal performance of the boiler is as planned and it fulfills the guarantee values.

Table 3. Some operation data

Variable	Plant load	Flue Gas CO	Flue Gas O2
Value and unit	35 MWth	50 ppm	4,5 %

The plant operation has been easy and is done remotely from the Naistenlahti Power Plant control room, 10 kilometers away. The operation of the boiler has been as expected. The plant master controller (district heating power or boiler water temperature) alters the boiler master that controls the fuel feed and combustion air. Table 3 shows some operational values of the plant.

6 CONCLUSIONS

Pulverized pellet firing offers a sustainable, high availability, safe and fully automatic alternative for district heating in larger district heating plants. The plant can be used to compensate the heat load requirements. Compared to other combustion technologies it offers fast load variation with moderate variable and fixed costs. High energy density and easy fuel handling makes it possible to use pellets also in urban surroundings. The Tampere plant shows an economical and technically feasible example of the very latest development in the field of renewal bioenergy. The plant solution was feasible for 500 to 3000 annual operating hours on full load. The operational experience of the boiler has been fulfilling the emission limits and the thermal guarantees. The boiler is remotely operated and has been used more than expected in the first hand, due to low electricity and pellet prices.

REFERENCES

Firefly. (July 1, 2012). www.firefly.se. Viewed in 2012 at Changing the World of Fire Protection.

Forsberg, B. (2012). Biomass powder burners. Technical datasheet. Nyköping, Sweden: WTS Ab.

Giacomo, G. D. & Taglieri, L. (2009). Renewable energy benefits with conversion of woody residues to pellets. Energy, 724–731.

Hansen, M. T.; Jein, A. R.; Hayes, S. & Betaman, P. (2009). Pelletatlas, English handbook for wood pellet combustion. Knowlhill: FORCE Technology/ EUBIA/ National Energy Foundation.

Klimstra J. and Hotakainen M. Smart Power Generation – The Future of Electricity Production. Wärtsilä Finland. Avain Publishers, Helsinki. 4th Improved edition. ISBN 978-952-93-1640-3. Printed in Arkmedia, Vaasa 2011

Koskela T., Orhanen J. and Heinonen T., Metso toimittaa Suomen suurimman pellettilämpölaitoksen Tampereen Energiantuotanto Oy:lle (In Finnish, Metso deliver the biggest pellet fired heat plant for Tampereen Energiatuotanto Inc.), Kraft and Drift, ISSN-0355-7081, 2/2012 p. 8, MIKTOR Helsinki, Finland 2012.

Lehtinen, Marjaana. (2012). A Pellet-fired Heating Plant. Results – Power, 1, 20–21.

Metso & Lehtinen. (1, 2012). A pellet-fired heating plant. results/power, Metso's customer magazine for power business line, pp. 20–21.

Obernberger, I. & Thek, G. (2010). The pellet handbook. London: Earthscan.

Swithenbank, J.; Chen, Q.; Zhang, X. & Sharifi, V. (2011). Wood would burn. Biomass & Bioenergy 35, 999–1007.

THE EMISSIONS DEPENDING ON THE EXCESS AIR RATIO FROM A SPACE-HEATING BIOMASS STOVE

Tomas Vonžodas, Lithuanian Energy Institute, Lithuania

Abstract: In all the European countries, as well in Lithuania, the residential heating with biofuel is applied using a variety of heating equipment: water-heating boilers, stoves, open and closed fireplaces and air heater. However, most of the devices are technically obsolete, not adapted for firing particular type of biofuels or just not properly equipped, so the heating system with such devices operate inefficiently and significantly increase environmental pollution.

Biofuel consumption structure analysis shows that recently the large part of biofuel is consumed by households. It is therefore very important improve parameters of heating devices used for residential heating.

In this paper the improvement of combustion process in biomass stove combustion chamber was investigated in order to increase thermal efficiency and to minimize emissions of carbon monoxide (CO), hydrocarbons (C_xH_y), nitrogen oxides (NO_X) and particulate in the combustion products.

During the experiments thermal parameters and emissions in combustion products were continuously recorded to gather information for further development actions. Some design corrections and proper application of stage combustion could reduce the CO and H_xC_y emissions up to 60%,

Increasing the excess air ratio the concentration of CO and H_xC_y decreased ~ 60%, but the NO_x concentration increased by almost 30%. Particulate concentrations of excess air ratio change had no effect. While increasing the coefficient of air excess, the coefficient of efficiency decreased by 3 presents.

Keywords: Space-heating stove; Biomass-fired stove; Stove emission; Combustion; Excess air ratio; Thermal efficiency

INCREASING FOREST GROWTH IN SOUTH SAVO REGION BY USING ASH FERTILIZATION

Soininen, H.[1], *Kontinen, K.*[2] *& Ranta-Korhonen, T.*[3]

[1] *Research Director, M.Sc. (Tech.), Mikkeli University of Applied Sciences, P.O. Box 181, 50101 Mikkeli, Finland. Tel. + 358 (0)400 869 952, e-mail: hanne.soininen@mamk.fi*

[2] *Research Manager, M.Sc. (For.), Mikkeli University of Applied Sciences, P.O. Box 181, 50101 Mikkeli, Finland, e-mail: kati.kontinen@mamk.fi*

[3] *Project Assistant, M. Sc., Mikkeli University of Applied Sciences, P.O. Box 181, 50101, Mikkeli, Finland, e-mail: tuija.ranta-korhonen@mamk.fi*

ABSTRACT: Project “Bio-fertilizers - More ash fertilization in the forest” was launched in the beginning of 2013. Project is partly EU-funded by South Savo Centre for Economic Development, Transportation and Environment. The project is jointly implemented by Mikkeli University of Applied Sciences and Finnish Forest Centre South Savo regional unit. Coordinator of the project is Mikkeli University of Applied Sciences. The aim of the project is to increase the utilization of wood and peat ash as a fertilizer in peatland forests by activating the local forest owners, forest officials, as well as agriculture and forestry entrepreneurs in South Savo. The main instrument to reach this aim is dissemination of knowledge. It is essential to direct the fertilization treatment to the right targets both from a silvicultural and environmental point of view and also to improve orderliness and cost-effectiveness of the action. The project will increase employment opportunities for rural enterprises, for example in ash fertilizer dispersion services. The project also helps to find more ecological and environmental-friendly ways to utilize the ash flows and to improve through fertilization the peatland nutrients balance and enhance tree growth and vitality.

Keywords: bioenergy, fertilization, fly ash, utilization, South Savo

1 SOURCES OF WOOD AND PEAT ASH AND THEIR CURRENT UTILIZATION IN SOUTH SAVO

One of the objectives of the Finnish national waste management plan is to reclaim 70 % of total amount of wastes from energy production. Amount of peat and wood ashes has nearly doubled in Finland during the last 10 years because of their increased use for energy production. Promotion of renewable energy sources in accordance with aims of European Union will constantly increase the amount of ashes generated by combustion of biomass [1]. In South Savo the energy consumption potential of forest energy is 1.8 million m^3, when nowadays in use is about 0.5 million m^3. It is realistic to assume, that in the nearest future the consumption of forest energy will double.

In project “Utilization and logistic flows of ashes from power plants using biomass for power generation in Eastern Finland” partly funded by EU, it was established that in the area of Eastern Finland (South Savo, North Karelia an North Savo) in power plants using biomass for power generation it is produced 100 000 tons of fly and bottom ash every year. In recent years the ashes of the area have been used in construction works of roads and landfill structures and in other earthworks but also in forest fertilization. The ashes from biomass combustion plants are nowadays mainly disposed of to the landfills, where they can be used as a substitute for natural materials. 28 % of ashes are directed to other utilization purposes (such as earthworks and forest fertilization) [2].

In 2008 about 21 400 tons of ashes were produced in South Savo region. In this amount are included bottom and fly ashes from the power plants. The biggest producers of ashes from biomass combustion in the region are Pursiala power plant of Etelä-Savon Energia Oy in Mikkeli, power plant of Suur-Savon Sähkö Oy in Savonlinna, Versowood Oy, Plywood mill of UPM Oy in Pellos, Ristiina, powered by Järvi-Suomen Voima Oy, plywood mill of Finnforest Oy in Punkaharju and power plant of Savon Voima Oyj in Pieksämäki. These plants produce approximately 93 % of total amount of ashes in the region. The share of the small producers of ashes (under 100 tons per year) is below 3 % of the total amount.

In South Savo region the ashes are mainly disposed of to the landfills of non-hazardous waste in Mikkeli (Metsäsairila Oy waste management centre) and Savonlinna (Savonlinnan seudun jätehuolto Oy waste management centre located in Nousiala). In North Savo region the ashes are landfilled in landfills of non-hazardous waste in Varkauden seudun jätehuolto Riikinneva waste centre located in Leppävirta, Ylä-Savon jätehuolto Oy waste centre in Iisalmi and Jätekukko Oy Heinälamminrinne waste centre in Kuopio. In North Karelia region the ashes are disposed of to the Joensuun Seudun Jätehuolto Oy Kontiosuo waste centre in Joensuu, which is also landfill for non-hazardous waste [2].

Furthermore there are privately owned landfills of various industrial plants in Eastern Finland region, which are also utilized for disposal of ashes. In the region utilization of ashes are promoted in bigger scale by FA Forest Oy, whose terminals and production plants are located in Ahonkylä, Liperi and in Viitasaari. In order to utilize ash flows of South Savo region more cost-effectively and ecologically in the future, there should be established intermediate storage areas and enterprises to process and exploit the ashes. Intermediate storage areas could be used in future as material banks to encourage utilization of by-product flows from the local industry [3, 4].

Intermediate storage areas could reduce the logistic costs and CO_2-emissions caused by transportation of ashes. Intermediate storing would also emphasize utilization of ashes for earthwork construction. Granulation and conversion of ashes to fertilizers could be carried out in so called ash terminal located in intermediate storage area in South Savo.

2 UTILIZATION OF ASH FOR FOREST FERTILIZATION IN SOUTH SAVO

The aim to increase utilization of renewable energy sources will double the use of forest converted chips in energy production in the becoming years, which will also increase the amount of ashes caused by the combustion of biomass. By using ash as a fertilizer it is possible to improve and correct nutrient balance of the peat soils and boost forest growth and vitality. Utilization of ashes for fertilization purposes is nowadays quite rare in South Savo comparing to the benefits, needs and possibilities of their use. This is among other things caused by the fact that ash fertilization and its impacts are not commonly known.

For forest fertilization purposes it is possible to use ashes from combustion of wood, peat or cultivated biomass. Ash from wood combustion should be hardened or granulated before using. The concentration of phosphorus (P) and potassium (K) should be together at least 1 %, calcium (Ca) at least 8 % and chloride (Cl) max 2 % from total solids in wood ash [5].

Obvious targets for utilization of ash fertilization are peat soils, ditched peatland forests. Peat soils usually contain enough nitrogen for forest growth and nutrition balance, but there is shortage of other primary nutrients, such as potassium and phosphorus [6]. Wood ash especially contains potassium and phosphorus in right proportion and is very suitable for fertilization of peatlands. Peat ash contains potassium less than wood ash, but is applicable for fertilization of phosphorus-poor peatlands when potassium is added. Mix of wood and peat ashes can be usable fertilizer as it is, or it can be refined by adding potassium and boron to ash [5].

According to the Forest programme of South Savo about 260 000 ha from the total 1.2 million ha forest area of the region are peatlands. About 210 000 ha of peatlands are converted to silvicultural use by ditching. The annual growth of ditched peatland forests is 1.6 million m^3 and harvesting possibilities over 1 million m^3. About 2/3 of peatlands forests are in the stage of commercial first thinning or young cultivated forests, future timber tree forest. Peatland forests offer at this moment also lots of energy wood in consequence of their young age distribution [7].

Fertilization treatment with ash can repair the nutrient balance of peatlands and also enhance growth of stand with the exception of the most nutrient-poor forest lands. About 15 % of the total area of peatlands is this kind of nutrient-poor, ditched peatland forest. This means that ash fertilization is suitable for the most of the peatlands and it can be applied to enhance the growth especially in the forest lands that suffer from nutrient imbalance. The annual increase of wood yield can be 1-6 m^3/ha during the life cycle of a stand and the influence of one fertilization treatment can last up to 40 years. Ash fertilization treatment has also been tried with good results for afforestation of previous peat-mining areas [5].

In certain ditched peatland forest the nutrient imbalance, that is the shortage of phosphorus and potassium, emphasizes in the middle and the end of the forest life cycle when amount of tree stock increases. There are in South Savo probably tens of thousands hectares of this kind peatland forest suffering clearly from the nutrient imbalance and which are thus primary targets for corrective fertilization [7].

Ash fertilization is not recommended treatment for moorlands in the raw because ash does not contain nitrogen. The most potential targets for ash fertilization are fertile moorlands in which stands suffer from growth disorders caused by the lack of boron. The majority of boron in wood is in stemwood, branches and stumps. Because of the effective harvest of energy wood boron is nowadays increasingly out bounded from fertile moorland spruce copses. With ash fertilization treatment it is possible to return boron back to forest growth cycle especially in the spruce forests with inadequate amount of boron. To increase the wood yield with ash fertilization treatment in the moorlands nitrogen should be added to ash [5].

3 FUTURE EVENTS OF THE PROJECT

Target groups of the Bio-fertilizers-project are forest owners, forest officials, as well as agriculture and forestry entrepreneurs in South Savo. Mikkeli University of Applied Sciences is organizing during the years 2013-2014 seminars for knowledge dissemination and for experts.

Work demonstrations of the project are targeted to forest officials, forest owners and future and present harvesting entrepreneurs. Work demonstrations are organized three times in the region of South Savo.

Work demonstrations take place in actual target areas for fertilization and they are organized in cooperation with different forest organizations, forest owners, ash fertilization manufacturer and fertilization spreading entrepreneur. In demonstrations fertilization is dispersed both by using mechanical applicator on the ground and via aerial application by helicopter.

Finnish Forestry Centre South Savo regional unit will carry out a study about the usability of peat and wood ash for forest fertilization treatment during the project. Aim of this study is to direct fertilization to the right targets both from silvicultural and environmental point of view.

4 REFERENCES

[1] Soininen, H., Mäkelä, L. & Valkeapää, A. 2010. Utilisation of Biofuel Consuming Energy Plants' Ash Material Flows in Eastern Finland. Session OD1.2 S. 190 - 194. (5 pages). Proceedings (CD) of the 18th European Biomass Conference and Exhibition From Research to Industry and Markets, Proceedings of the International Conference held in Lyon, France 3 - 7 May 2010. ISBN 978-88-89407-56-5.

[2] Soininen, H., Mäkelä, L., Kyyhkynen, A., Muukkonen, E. 2010. Biopolttoaineita käyttävien energiantuotantolaitosten tuhkien hyötykäyttö- ja logistiikkavirrat Itä-Suomessa. Mikkelin ammattikorkeakoulu, A: Tutkimuksia ja raportteja nro 59. 111 s. ISBN978-951-588-303-2.

[3] Soininen, H., Luste, S. 2012. Utilisation and Quality of Ash Material Flows from Biofuel Consuming Energy Plants in Eastern Finland. Pag. 254 - 261. In: Book of Proceedings (CD) of the International Bioenergy from Forest 2012, Conference held in Jyväskylä, Finland 27.8. - 31.8.2012. Editor BENET. 263 p.

[4] Soininen, H., Kontinen, K., Luste, S. 2012. Quality and Characteristics of Ash Material from Energy Plants in Eastern Finland. Session 4BV.4.15, pag. 1963 - 1967. Proceedings (DVD) of the 20th European Biomass Conference and Exhibition (EU BC&E 2012), Proceedings of the International Conference held in Milan, Italy 18 - 22 June 2012. ISBN 978-88-89407-54-7.

[5] Makkonen, T. (toim.) 2008. Tuhkalannoitus. Metsätalouden kehittämiskeskus Tapio. Tuotenumero 1197. Metsäkustannus Oy. 31 s. ISBN 978-952-5694-36-9.

[6] Ahtikoski, A., Hökkä, H., Joensuu, S., Kojola, S., Kuusela, M., Moilanen, M., Penttilä, T., Ruotsalainen, M., Saarinen, M. 2007. Turvemaiden metsien käsittely- ja hoito. Laskelmia ja tutkimustietoa taustamateriaaliksi turvemaiden metsänhoitosuositusten kehittämistä varten. Metsätalouden kehittämiskeskus Tapio. 132 s.

[7] Vento, P., Repo, S., Karppinen, H., Granander, M. (toim.) 2011. Etelä-Savon metsäohjelma 2012 - 2015. Suomen metsäkeskus, Julkiset Palvelut, Etelä-Savo. 52 s.

PERFORMANCE OPTIMIZATION OF BIOMASS RECIPROCATING GRATE FIRED BOILER

Charlotte Marty, Leroux et Lotz Technologies, 10, rue Irène Joliot Curie, F-38320 Eybens, France, +33 (0)4 76 14 77 95, fax: +33 (0)4 76 14 01 23, charlotte.marty@lerouxlotz.com
Co-authors:
Tudor Florea, Leroux et Lotz Technologies, F-38320 Eybens, France, tudor.florea@lerouxlotz.com
Waldemar Kalinowski, Eurobiomass Polska, ul. Grochowska 43, 82300 Elblag, Poland, w.kalinowski@eurobiomass.pl
Mazen Al Haddad, Leroux et Lotz Technologies, F-38320 Eybens, France, mazen.alhaddad@lerouxlotz.com

Abstract: In a context where the development of renewable energies is a priority of the European government's energy policies, biomass appears to be a promising resource to achieve 2020 EU objectives. Therefore the use of biomass for combustion is increasing significantly, leading to an extension of the types of biomass used as raw material. Moreover, the Industrial Emission Directive (IED) 2015 aims to stricter emissions limit values. As a consequence, combustion technologies need to be optimized in order to become more flexible toward a wide range of biomass available resources (woody biomass, agricultural biomass, forest residues, energy crops, etc.) while enhancing the efficiency and environmental performances. Medium scale biomass boilers (1-10 MW) are widely used for heat production. These boilers present the advantage of having higher performances than individual biomass boilers due to a more complete regulation system and a reduced flue gas outlet temperature. Nevertheless, they suffer from low performances when used with low quality biomass fuels. In order to reduce the sensitivity of the reciprocating grate fired boilers performances due to biomass quality variations, Leroux et Lotz Technologies has conducted an extensive R&D project. A CFD modeling approach was investigated, validated and completed with an experimental program that was performed on different industrial biomass grate fired boilers. Experiments were lead in order to study the impact of combustion parameters on boiler performance, and in particular on thermal efficiency and emission levels. The experimental results were used to evaluate the available combustion control techniques and determine the best combustion parameters with regards to biomass properties. The CFD model is used as a tool to define new improved boiler configurations and also to investigate the post-combustion methods for pollutant emissions abatement. Through this project, combustion and post-combustion control techniques were optimized. This work has led to optimal combustion parameters adapted to the biomass quality and to evaluation of post-combustion reduction methods requirements in order to reduce emissions.

USING CATALYSTS TO REDUCE THE EMISSIONS FROM A NEW BIOMASS SMALL SCALE COMBUSTION UNIT

R. Bindig [a], S. Butt [a*], D. Dvoracek [b], D. Enke [b], I. Hartmann [a], F. Werner [c]
[a] DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Straße 116, Leipzig 04347, Germany
[b] Universität Leipzig, Institut für Technische Chemie, Linnéstraße 3, 04103 Leipzig, Germany
[c] Specht Modulare Ofensysteme GmbH & Co, KG, Bahnhofstr. 2, 35116 Hatzfeld, Germany
*Corresponding author. Tel.: +49 341 2434 425 email address: Saad.Butt@dbfz.de

ABSTRACT: A newly designed downdraught wood stove achieved low-emission heating by integrating an alumina-supported mixed metal oxide catalyst in the combustion chamber operated under high temperature conditions. In the first step, a catalyst screening has been carried out with a lab-scale plug flow reactor in order to identify the potentially active mixed metal oxide catalysts. In this regard, spinel catalysts have been the center of attention because of their expected high temperature stability and activity. The monolithic catalyst has been synthesized through a novel route called "Reactive Surface Solid Activation (RSSA)", and it has been integrated into the downdraught wood stove. The alumina-supported metal oxide catalyst reduced the volatile hydrocarbons and carbon monoxide emissions by more than 70 %. The carbonaceous aerosols were also abated by more than 60 %.

Keywords: Small scale biomass combustion, Mixed metal oxide, Catalysts, Emission reduction, Pressure drop

1 INTRODUCTION

The use of biomass or bioenergy can be traced back to the beginning of human civilization when people started to burn wood for heating and cooking purposes. Ironically, after so many years have gone by, wood still remains the largest biomass resource in the world [1]. However, one major difference which has occurred over this period of time is the introduction of the concept "modern biomass" which states the usage of traditional biomass resources in highly efficient systems. This concept has been put into practice with more conviction and determination during the last decade, particularly in Europe, due to ever rising CO_2 levels in our environment. By now, it is an established fact that about 10-30 % of total energy demand for hot water supply and domestic heating in European countries like, Austria, Germany, Sweden and Finland is provided by small scale biomass combustion systems [2]. Moreover, it has been also concluded that despite the vast spread of technologically advanced small scale combustion devices in European countries (like countries mentioned above) during the recent years, still the old biomass combustion systems (stoves and boilers) occupy more consumers [3]. These conventional systems which are based on natural draught play a pivotal role in contributing to the high emission levels of particulate matter (PM), carbon monoxide (CO), organic gaseous compounds (OGC) and polycyclic aromatic hydrocarbons (PAH). These facts and figures have triggered an enormous understanding and awareness among the researchers as well as local population concerning harmful emissions coming out of such residential biomass systems. For this reason such inefficient small scale biomass combustion systems have been heavily criticized and demanded to be replaced by new efficient technologies.

Speaking of older and newer technologies, it has to be mentioned here that two types of technologies exist involving small scale biomass combustion systems. The old biomass combustion systems are based on "over-firing" which is in a process of being rapidly replaced by "down-firing" systems (new technologies). As mentioned above, these older systems are a main source of PM_1 (particles with diameter less than 1 µm) in European countries. It has been also concluded that such particles serve as a purpose of "support" onto which carbonaceous particles (organic compounds and soot) are deposited which are primarily responsible for the adverse health effects [4]. So in order to counter such an undesired release of pollutants, particularly from small scale biomass systems, a concept has been conceived according to which "down-firing" technology will be implemented in specially designed wood log stove in combination with catalytic treatment in order to abate harmful emissions to minimum possible values. It is noteworthy to mention here that the abatement of emissions through catalytic treatment from small scale biomass combustion systems has not been studied or implemented on a wide scale. So this novel concept of integrating catalytic components in different parts of the stove i.e. grate, walls of combustion chamber and the base will open more channels and schemes in order to accomplish the acceptable emission levels coming out of biomass combustion systems particularly, those used for residential purposes.

In the past, the process of catalysis has been strongly linked to chemical and refinery industries. However, recently the catalytic converters have been deployed and installed in automobiles, biomass fired boilers, power generation facilities etc. in order to promote the environmentally friendly usage of technological devices. It has been estimated that the market of catalysis around the world worth around US $ 9 billion, out of which, one third is occupied by the environmental catalysis. So building on this ever growing trend of environmental catalysis, this article gives a further insight into the integration of catalytic components in a wood log stove to foresee the feasibility of this novel approach to resolve the problem of high emissions (e.g. carbon monoxide, volatile organic compounds, dust particles etc.) coming out of small scale biomass combustion systems.

2 MATERIALS AND METHODS

A test bench has been developed (as shown in the Figure 1) in order to examine the emissions from a prototype stove manufactured by the company Specht GmbH & Co.KG. The test bench is designed in such a way that it can facilitate the analysis of dust composition, based on full flow dilution measurements, during the future experiments. However, the dilution tunnel measurements are not included during the preliminary stages of this project.

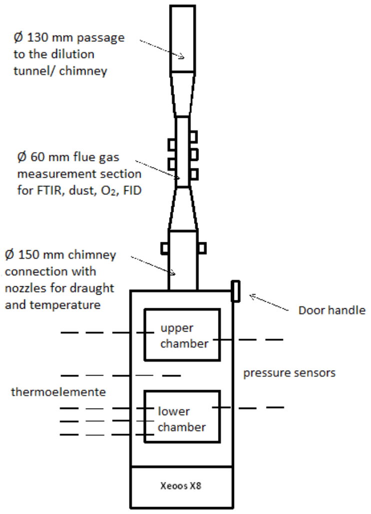


Figure 2: Illustration of the test bench with a flue gas measurement section (hot) for the emission measurement

For the determination of flue gas and combustion chambers temperature profiles, the thermocouples of Type K (manufactured by the company "Newport Electronics GmbH") have been used. The measurement of static and dynamic pressures in the flue gas has been done with the aid of Prandtl tube produced by the company "Testo AG". The continuous transmitting and data recording of Prandtl tube and pressure nozzles in the combustion chamber is carried out through data logging module provided by the company "Ahlborn". The data of the thermocouples have been recorded through a data logger of the company "National Instruments" along with the help of the software "Labview".

The emissions coming out of the stove are measured by means of a gas analyzer which consists of a Fourier Transform Infrared Spectrometer (FTIR, Manufacturer: Calcmet), a Flame Ionization Detector (FID, Manufacturer: Mess- & Analysentechnik GmbH, Typ: thermo-FID ES) and a paramagnetic oxygen analyzer (Manufacturer: M&C, Type: PMA 100). The infrared spectrum of FTIR can measure simultaneously organic as well as inorganic components. At the moment, about 44 different components can be recorded through FTIR.

The VOC-Emissions can be recorded by means of both FID and FTIR measuring devices. In case of Org.-C, the concentrations ranging under 50 mg/m^3 (at standard conditions i.e. = 0 °C, 1 atm) can be considered from the FID measuring device. On the other hand, the values above 50 mg/m^3 (at standard conditions i.e. = 0 °C, 1 atm) can be assumed from the FTIR measuring device. Following parameters can be measured simultaneously:

1. Oxygen O_2 (paramagnetic analyzer)
2. Carbon dioxide (FTIR)
3. Moisture in the flue gas H_2O (FTIR)
4. Carbon monoxide CO (FTIR)
5. Volatile organic compounds (VOC) as organic carbon (Org.-C) (FTIR and FID)
6. Nitrogen oxide as nitrogen dioxide equivalent (NO_{2equi}) (FTIR)
7. Sulphur dioxide SO_2 (FTIR)
8. Methane CH_4 (FTIR)
9. Organic compounds like, alkanes, alkenes, aromatics, aldehydes as well as ketones (FTIR)
10. Flue gas temperature, gas velocity and draught conditions.

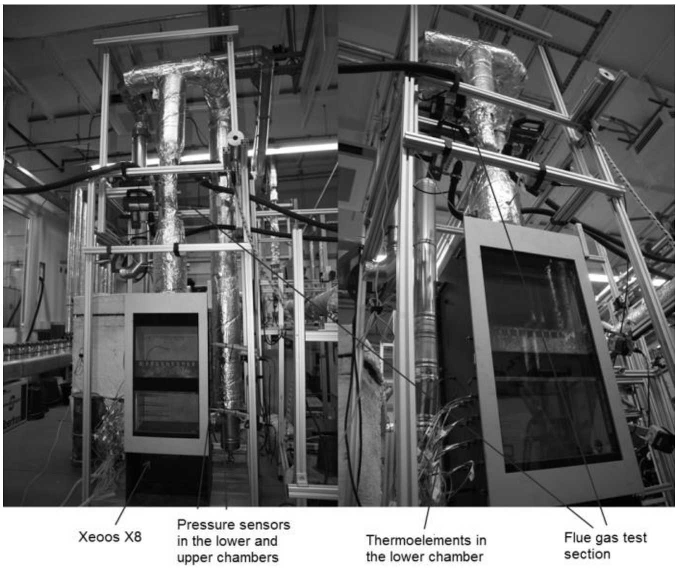


Figure 3: Illustration of the test bench for the measurement of emissions from the stove xeoos-X8

The recording of the above mentioned parameters took place on continuous time basis except for the dust measurement. During the evaluation of the data, the average values of the pollutants were calculated for each dust sampling cycle whereas each cycle lasts for 30 minutes. With the aid of a chimney fan, a constant negative pressure of 12 Pa has been maintained in the chimney stack in order to achieve a fuel thermal output from 8 to 9 kW.

The gravimetric analysis of total amount of dust was done in accordance with VDI guidelines 2066, according to which a partial volume flow must be taken isokinetically out of the main flue gas stream. In the process, the accompanied particles can be deposited on the already weighed plane filter. Since the filter housing is located outside the flue gas pipe, this sampling procedure is termed as "out stack process". The filter system was heated up with a heating jacket in order to prevent the falling down of saturation temperature of the flue gas. The temperature of the filter was maintained at 70 °C so that the semi-volatile hydrocarbons could also be deposited in particulate form on the filter and could be chemically analyzed by means of GC/MS. After the experiment, the deposited dust amount was determined gravimetrically and then can be specified by taking into consideration the measured partial volume and oxygen concentration. The plane filter was made of micro-glass fibres having a diameter of 45 mm.

3 RESULTS AND DISCUSSION

3.1 Reference experiment

At first, a reference experiment was carried on the xeoos-stove in order to determine the emissions, temperature profiles and pressure conditions during the operation of the stove in an unmodified state. This reference test is vital in the context of evaluating the effect of different modifications and changes in the stove which will be done in upcoming experiments. The temperature profile was recorded with the aid of thermocouples which were inserted into the grate, in the middle of lower and upper combustion chambers as well as in the walls of the lower combustion chamber. Moreover, the pressure conditions were recorded with the help of pressure sensors, inserted into the combustion chambers (upper and lower) as well as into the exhaust pipe. In the Figure , the temperature profiles of different sections of the stove have been depicted. For the every burn-up cycle, the stove was operated for the first 30 seconds in upper burning mode. After that, it was operated in down-burn (Twinfire mode) for the next 29.5 minutes. The average temperature in the grate was calculated to be around 600 °C whereas, the temperature in the walls of the lower combustion chamber, where catalysts are planned to be installed in future experiments, was found to be ca. 650 °C. In the Figure 4, the time-dependent behavior of CO, VOC (Org.-C) and aromatics (sum) has been depicted. These concentrations are recorded for four burning cycles of the reference test.

Table 4: Emission values during the reference test

Experiment	Emission values
Unit	mg/m^3 i.N., 13 % O_2
CO	1514
Org.-C	132
Aromatics (sum)	26,3
Dust	37

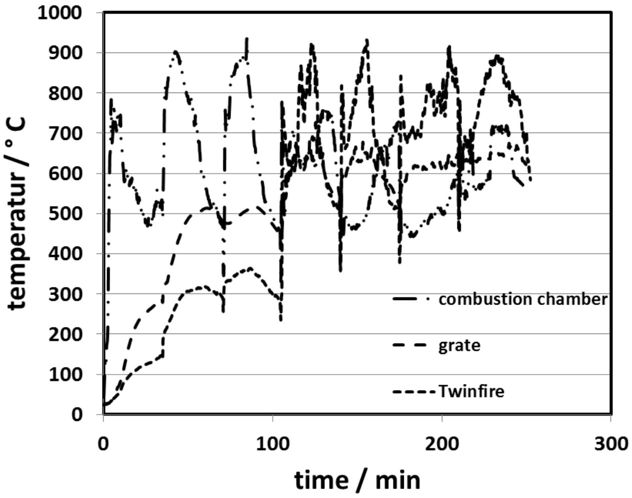
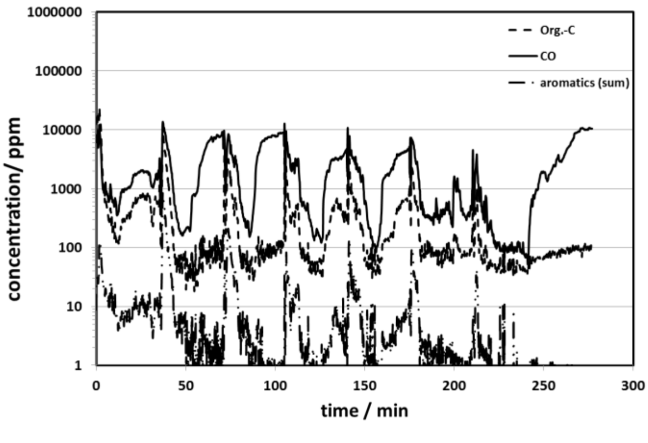


Figure 3: Time-dependent behavior of temperature during the reference experiment



3.2 Integration of foam as a support material (uncoated) in the side-walls of lower combustion chamber

Al_2O_3-foams were tested as a possible support material for a suitable catalyst at the start of the experimental stage. For this purpose, two such foams were inserted into the walls of the lower combustion chamber as shown in the Figure 5. However, first of all it was important to calculate the pressure drop across the monoliths in order to ascertain the smooth operation of the stove after installing the monoliths. The pressure drop across the monoliths was found to be 0.33 Pa which is sufficiently low and shows the applicability of the foams.

Figure 5: A photograph of the experimental setup with Al_2O_3-foams in the lower chamber

3.3 Integration of the catalyst in the side-walls of lower combustion chamber

3.3.1 Wall catalyst based on aluminium oxide foam of size 1

As observed, there is no negative effect on the combustion behavior of the stove after installing the uncoated Al_2O_3 foams so it leads to the testing of coated monolith with mixed metal oxides in the combustion chamber. As evident from the Table 2, after the catalyst incorporation, the emissions of CO and VOC (Org.-C) have been reduced by 21 % and 42 % respectively (in comparison to the reference test). Moreover, the dust emissions are also abated by 55 %.

Figure 6: A photograph of experimental setup with installed coated monoliths

Table 5: Reduction in emissions after integrating MnO_x/Al_2O_3-foams (size 1: 90 × 200 × 20 mm^3)

Experiment Unit	Reference mg/m³ i.N., 13 % O_2	MnO_x-foam mg/m³ i.N., 13 % O_2	Reduction %
CO	1514	1201	21
VOC (Org.-C, FID)	109	63	42
VOC (Org.-C, FTIR)	132	83	37
Dust with rinsing	37	17	55
Dust without rinsing	33	14	57

3.3.2 Wall catalyst based on aluminium oxide foam of size 2

In order to further reduce the emissions from the downdraught stove, coated monoliths with MnO_x of relatively greater active catalytic surface, as compared to the earlier tested monoliths, have been incorporated into the stove. The concentrations of CO and VOC are reduced by 67 % and 72 % respectively, as shown in the Table 3 (in comparison to the reference test). The dust emissions are also cut down by 68 %.

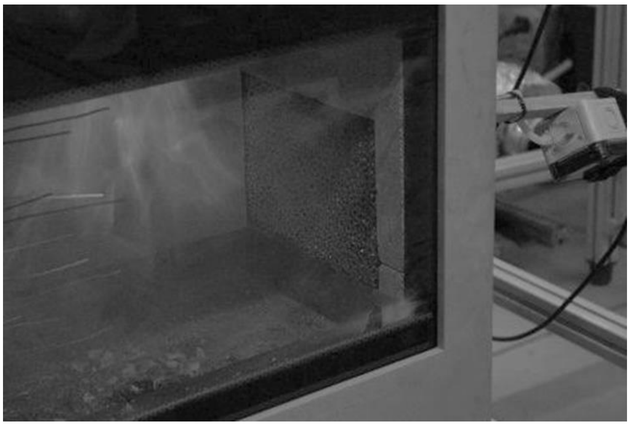


Figure 7: A photograph of experimental setup with bigger Al_2O_3-foams (size: 140 × 200 × 20 mm³)

Table 3: Reduction in emissions after integrating MnO_x/Al_2O_3-foams (size 2: 140 × 200 × 20 mm³)

Experiment Unit	Reference mg/m³ i.N., 13 % O_2	MnO_x-foam mg/m³ i.N., 13 % O_2	Reduction %
CO	1514	499	67
VOC (Org.-C, FID)	109	30	72
VOC (Org.-C, FTIR)	132	59	55
Dust with rinsing	37	12	68
Dust without rinsing	33	11	67

3.3.3 Increase in the reduction of pollutants by the wall catalysts after the induction of heat reflecting plate

In order to lower the emissions coming out of the stove, the temperature in the lower combustion chamber was increased by placing a heat reflecting plate in front of the door in the lower combustion chamber as shown in the Figure 8.

Figure 8: Photograph of experimental setup with heat reflecting plate in the lower chamber

Table 4: Reduction in the emissions after integrating MnO_x/Al_2O_3-foams (size 1: 90 × 200 × 20 mm^3) with heat reflecting plate

Experiment Unit	Reference mg/m³ i.N., 13 % O_2	MnO_x-foam mg/m³ i.N., 13 % O_2	Reduction %
CO	1514	578	62
VOC (Org.-C, FID)	109	16	85
VOC (Org.-C, FTIR)	132	35	74
Dust with rinsing	37	11	71
Dust without rinsing	33	10	70

The influence of heat reflecting plate has been analyzed on the larger MnO_x/Al_2O_3-foams (140 × 200 × 20 mm³). The fitting of the heat reflecting plate is done in the same manner as in case of smaller MnO_x/Al_2O_3 – foams (90 × 200 × 20 mm³). As depicted in the Table 5, the emissions of CO and VOC are reduced by 87 % and 92 % respectively. Furthermore, the dust measurements are reduced by 76 %.

Table 5: Reduction in the emissions after integration MnO_x/Al_2O_3-foams (size 2: 140 × 200 × 20 mm^3) with heat reflecting plate

Experiment Unit	Reference mg/m³ i.N., 13 % O_2	MnO_x-foam mg/m³ i.N., 13 % O_2	Reduction %
CO	1514	193	87
VOC (Org.-C, FID)	109	9	92
VOC (Org.-C, FTIR)	132	34	74
Dust with rinsing	37	9	76
Dust without rinsing	33	8	76

3.3.4 Aging behavior of the wall catalyst MnO_x/Al_2O_3

For the determination of the thermal and chemical deactivation of the catalyst, it has been aged by fitting it into a model stove at the company/manufacturer “Specht GmbH & Co.KG” and subjected to practical operating conditions for ca. 185 h. After that, the aged catalyst is analyzed at DBFZ-test bench to investigate its stability. The results have indicated that, as shown in Table 6, the catalyst MnO_x/Al_2O_3 showed no signs of deactivation during the testing.

Table 6: Reduction in the emissions after the integration of the aged catalyst (size 1: 90 × 200 × 20 mm^3)

Experiment Unit	Reference mg/m³ i.N., 13 % O_2	MnO_x-foam mg/m³ i.N., 13 % O_2	Reduction %
CO	1514	833	45
VOC (Org.-C, FID)	109	33	70
VOC (Org.-C, FTIR)	132	n.a.*	n.a.*
Dust with rinsing	37	15	59
Dust without rinsing	33	14	58

´* not available because of a problem with the measuring equipment

However, the aging of the larger coated monoliths (size 2: 140 × 200 × 20 mm^3) has not been tested so far but is planned during the upcoming experiments.

3.4 Cylindrical ceramic monolith as a support material for the grate catalyst

In addition to the wall catalysts, an integration of the grate catalyst has been thought of as a way to further reduce the emissions from the prototype stove "xeoos". In order to integrate the grate catalyst in the stove, a stainless steel tube has been fitted as a mounting directly under the double plate of the grate as shown in the Figure 9. It will allow monoliths of different cylindrical dimensions to be incorporated into the steel tube. The aim of this experiment is to analyze the pressure drops and possible changes in the temperature profile of the chamber. In addition, the examination of the suitability of the ceramic monolith, made of corundum or other ceramic material, can be carried out.

Figure 9: Photograph of the stainless steel tube containing an uncoated monolith directly under the grate

Table 7: Emission values after the integration of the uncoated cylindrical monolith directly under the grate

Pollutants unit	Emission values mg/m^3 i.N., 13 % O_2
CO	1723
VOC (Org.-C)	143
Dust	28

The annular gap between the monolith and stainless steel tube was filled up by an isolation material (made of silicon fibers). However, during the course of the experiment, the isolation material experienced severed contraction and expansion due to the heating and subsequent cooling during the charcoal burn out phase which resulted into stress at the monolith, thus causing it to shear off. The results obtained through this experiment are promising and in future, the monolith can be coated with a potentially active catalytic material out of mixed metal oxides to yield low emissions during combustion.

4 CONCLUSIONS

The selected monoliths, primarily composed of aluminum oxide (Al_2O_3), are coated with metal oxides like manganese oxide (MnO_x) act as an active catalytic material, which are later inserted into the walls of the stove in the lower combustion chamber. These Al_2O_3 foams with the porosity of 10 ppi consist of 92 % α-Al_2O_3 along with the trace phases of mullite and cordierite. The results have revealed that the catalyst i.e. MnO_x is found to be quite active in terms of conversion of harmful pollutants e.g. CO and Org.-C. Moreover, two different sizes of coated monoliths have been tested in the stove and it can be concluded that the bigger monoliths showed improved conversion concerning the pollutants (with smaller: CO = 21 %; Org.-C (FTIR) = 37 %, with bigger: CO = 67 %; Org.-C (FTIR) = 55 %). In addition, a heat reflecting plate has been fitted in the lower combustion chamber so that the temperature at the coated monoliths can be increased to get a better catalytic conversion. For the purpose of developing a downstream grate catalyst, a stainless steel tube has been integrated directly under the grate in order to examine its suitability as a catalyst mounting which showed quite positive results. Therefore, in future, different support materials can be coated with an active catalytic material and later on tested as a potential downstream grate catalyst using this concept. In short, a stove based on downdraught technology along with fitted and integrated catalytic components can achieve very low level emissions during its operation.

ACKNOWLEDGMENTS

We deeply appreciate the cooperation and support of our project partners i.e. University Leipzig (Institute of technical chemistry), Deutsche Bundesstiftung Umwelt (DBU) as well as Specht Modulare Ofensysteme GmbH & Co, KG within the scope of this project. Without their support, it was not possible to achieve such positive results which would have eventually resulted into termination of this project. In this regard, we would like to express our gratitude to the University Leipzig for their help in preparing and analyzing desired catalysts, Deutsche Bundesstiftung Umwelt (DBU) for their financial support and Specht Modulare Ofensysteme GmbH & Co, KG for providing their prototype stove for testing.

5 REFERENCES

[1] Demirbas A. *Biofuels*. London: Springer; 2009.
[2] Junginger H, Jonker J, Faaij A, Cocchi M et al. *Summary, synthesis and conclusions from IEA Bioenergy Task 40 country reports on international bioenergy trade.* IEA Bioenergy; 2011.
[3] Jokiniemi J, Hytönen K, Tissar J et al. Biomass combustion in residential heating: Particulate measurements, sampling, and physicochemical and toxicological characterization. Finland: University of Kuopio, Fine Particle and Aerosol Technology Laboratory; August 2008,92 p.
[4] Kelz J, Obernberger I, Jalava P, Hirvonen M. PM emissions from old and modern biomass combustion systems and their health effects. 2010; 18th European Biomass Conference and Exhibition: 1231-1243.

WHAT LESSONS CAN BE LEARNED FROM THE IMPLEMENTATION OF THE RENEWABLE HEAT INCENTIVE (RHI) ON THE UPTAKE AND INSTALLATION OF BIOMASS SYSTEMS IN THE UK?

David Linsley-Hood, Buccleuch BioEnergy Ltd, Computer House, Dalkeith, Edinburgh, EH22, dlinsley-hood@buccleuch.com
Co-authors: Des McGinnes, dmcginnes@buccleuch.com
Andy Wiseman, awiseman@buccleuch.com
Graeme Ogilvie, gogilvie@buccleuch.com

The Renewable Heat Incentive (RHI) is a unique driver developed to provide financial assistance to the implementation of thermal renewable energy technologies in the UK. Over the past 16 months, many lessons have been learned related to the successful implementation of this system, including the impact on metering and sustainable fuel supply. This study aims to highlight the key areas of success and failure of the programme, and provide insight into the possible areas of investment in the UK market going forward.

Approach: BBL is a specialist supplier and installer of industrial and commercial scale biomass boiler systems. Our company is a distributor for both Austrian and Finnish boiler technology in the UK, and has a wide range of experience in delivering turnkey installations as well as ESCo contract arrangements.

The approach of this report is based around the evaluation of government statistics and consultation documents, combined with insight from leading bioenergy firms to provide an independent assessment of the current state of the UK bioenergy market.

Scientific innovation and relevance: The relevance of this study is around the lessons learned from the implementation of the UK RHI scheme, and the market opportunities available that this has presented.

Results: At the time of writing, 322MW of commercial Renewable Heating systems have applied for registration under the RHI scheme. 97% of this has been from Biomass Boilers. However for the second year running, the uptake in applications have been below the target level, with only 1/3rd of the available budget allocated to existing installations.

Several factors have contributed to this lack of uptake: Consumer confidence in bioenergy technologies; fuel chain availability; requirements for metering; emissions criteria; high costs of finance. Installations over 1MW have also been affected directly by the low level of the RHI incentive at this level.

However investor confidence is high in many areas, with a wide range of investors offering packaged biomass schemes focussed directly around the delivery of ESCO type energy supply arrangements.

Conclusions: Overall, the situation in the UK market is buoyant, with significant development in the implementation of biomass. Many lessons can be learned from this period of expansion.

FLUE GAS TREATMENT AND ENERGY EFFICIENCY – NEW TECHNOLOGIES BY CALIGO INDUSTRIA OY

Juha Järvenreuna and Mika Nummila, Caligo Industria Oy, FInland

Our Company

The words ”Caligo” and “Industria” come from Latin and mean “smoke” and “energetic” respectively. These words are the basis of our company and its know-how. We develop and market technology solutions for cleaning energy and process industry flue gases and for recovering process waste heat.

Our technology solutions represent the highest innovation levels and best know-how in our field. We combine the most advanced theories of thermodynamics and flow mechanics with extensive practical experience in energy and process industry related challenges.

Our basic philosophy is to offer our customers the best innovations and patented solutions with the shortest payback periods possible.

We are part of Elomatic Ltd; a leading European consulting and engineering company and have a resource and skill base of over 700 competent engineers at our disposal. Caligo’s offices are located in Turku and Jyväskylä.

Flue gas scrubber

Our core product is a highly advanced flue gas scrubber solution, which is designed and optimized according to the total heat power output, fuel content and specific temperature rates of heating plant processes. We deliver flue gas scrubber solutions for heating plants ranging from 1 MW to 20 MW.

Remarkable savings with heat recovery solution

The strong performance of our heat recovery solution is based on our patented heat pump connection, which raises heat recovery to a completely new level. In addition, the heat pump connection ensures maximum heat recovery when return flow temperatures in district heating networks increase above normal levels. This temperature rise results in dramatic heat recovery losses when traditional flue gas scrubbers are in operation. The use of our heat pump module in conjunction with a traditional flue gas scrubber unit results in savings of even over 30% of the total annual fuel cost – especially in cases where there is a desire to minimize oil requirements.

Small footprint reduces investment costs

We utilize advanced technologies in condensate treatment. After treatment the condensate can be channelled to traditional sewer networks without any additional treatments. Due to our patented treatment process the solution footprint is less than half that of traditional treatment processes. The small footprint ensures further savings in plant infrastructure investment costs.

Fulfils the latest EU particle emission limits

The flue gas scrubber solution fulfils all the latest and increasingly demanding particle emission limits set by the European Union. We are also currently developing a new NOX treatment module that will be available in 2014.

Fast delivery and installation

Our flue gas scrubber solution is a compact unit. It is delivered as a single unit ready for installation. Most of the test trials have already been run at the manufacturing site as part of the manufacturing process. At the installation site the unit is connected to the plant process. After that it’s operationally ready. We boast the shortest delivery times on the market, which ensures the shortest possible delay in achieving operational savings from the time of investment to the actual implementation.

Independent operational unit

Our flue gas scrubber is an independent operational unit that does not require changes to plant operation or impact negatively on reliability or performance. The complete unit is connected to the flue gas exhaust piping right after the boiler process. The basic unit is provided with an independent automation system, which optimizes the functionality of the system and adjusts its operation to the rest of the plant’s processes.

Online monitoring and helpdesk services

We provide advanced online monitoring and help desk services via the Internet to our customers. Our support expertise ensures the best performance of the flue gas scrubber throughout your operational year.

CHEMICAL BIOMASS CONVERSION PRODUCTS

LIQUEFACTION OF BIOMASS: AN OVERVIEW OF NEW APPROACHES AND TECHNIQUES

M. Hakki Alma1, Tufan Salan2, Ertugrul Altuntas1, Eyyüp Karaogul1*

1Department of Forest Industrial Engineering, Faculty of Forestry, Kahramanmaras Sutcu Imam University, 46100, Kahramanmaras, Turkey, E-mails of co-authors: e.karaogul@ksu.edu.tr, ealtuntas@ksu.edu.tr

2Department of Bioengineering and Sciences, Kahramanmaras Sutcu Imam University, 46100, Kahramanmaras, Turkey, E-mail: tufansalan@ksu.edu.tr

**Corresponding author (M. Hakki Alma). E-mail: alma@ksu.edu.tr*

Abstract

Nowadays alternative resources have been very imported for both chemical and fuel production due to decreases of petroleum reserves and increases prices of petroleum based fuels. Biomass derived sources are the most attractive feedstock among these alternative resources and have a high potential to produce both valuable chemicals and biofuels. Because of abundance, easy availability, carbon neutrality, clean and eco-friendly features of biomass, there is a growing interest in green chemicals and fuels. Currently there are three main platforms includes thermal, sugar and oil (algal and vegetable oils) for the biomass conversion to chemicals and fuels in the biorefinery concept. Liquefaction process is one of the well-known oldest methods among the thermochemical biomass conversion routes and there is an increasing interest in biomass liquefaction. Liquefaction process can be divided two main subtitles: Indirect liquefaction (Gasification+ Fisher-Tropsch) and direct liquefaction includes fast pyrolysis, hydrothermal liquefaction and solvolysis liquefaction. Liquefaction is a
promising technology to convert biomass to liquid valuable products via complex chemical and physical reactions. In this process, basically heating, various catalysts or pressure are used as individually or together to separate macromolecular substances into small ones. Several authors have been intensively studied about the conventional liquefaction of wood and other biomass based materials. However, especially in the last decade scientists have focused new liquefaction approaches and techniques in order to improve the cost, yield and duration of process, range and features of products and to achieve a sustainable renewable chemical and biofuel production. Researchers have investigated several new methods, such as sub and supercritical solvent liquefaction, microwave-assisted liquefaction, ultrasound-assisted liquefaction, ionic liquid assisted hydrolysis, catalytic fast pyrolysis and patented low temperature pressureless catalytic depolymerization (KDV Technology).

The aim of this study to review these novel biomass liquefaction methods and their principles, and pay attention to importance of biomass derived liquid biofuels and valuable chemicals such as phenolic compounds that can be used for producing phenolic resins; furfural, levulinic acid, HMF (hydroxymethylfurfural), .-valerolactone that can be further upgrade to liquid hydrocarbon fuels and methanol that is a raw material for many chemicals. A significant majority of the main transportation fuels and, new type adhesives, foams and molded wood products could be obtained from liquefied biomass particularly biomass wastes in the near future. As a result, biomass liquefaction has a great potential, for this reason new and renewable approaches and techniques have to be developed to improve the efficiency of process and property of product and finally it has to been emphasized the importance of the subject very well.

Key words: Liquefaction, biomass, liquid biofuels, bio-based chemicals, new methods

MODERN APPLICATION PROCEDURE FOR FARM MANURE DIGESTION USING HLAD PROCESS

Heikki Kutinlahti
MK Protech Oy
Yliopistonkatu 21 A 13, 40100 Jyväskylä Finland
heikki.kutinlahti@mk-protech.fi

ABSTRACT: One economical and very practical way to digest farm manure is to use high loaded digestion method (HLAD process). The manure sludge is first dewatered for thicker slurry digestion. Separated liquid with high nitrogen content is used directly as fertilizer in the field. Liquid separation decreases amount of digesting solid substrate and reduces also remarkably needless nitrogen in the digestion process. After dewatering of the outlet digestate the reject liquid contains nitrogen as ammonia form being again very usable fertilizer in the field. Liquid separation collects most of the phosphorous in the solid fraction and avoids too high phosphorous content in the fields. The dewatered end product can be utilized best where phosphorous is not troublesome – for example in greenhouses, soil improvement, etc.
Using HLAD process the biogas energy production and end product recycling are enough to cover AD plant costs when the farm manure amount is enough big. The dry solid amount of 10 tons per day guarantees basic economy for farm digestion plant. This means a farm of about 2 000 cows or 30 000 pigs.
Manure amount can be produced in some cases in one farm. Very usable way is to build a consortium of several farms and to collect the manures into the centralized HLAD plant.

KEYWORDS: Manure digestion, manure separation

MODERN APPLICATION PROCEDURE FOR FARM MANURE DIGESTION USING HLAD PROCESS

All kind of manures of cows, pigs, poultry, etc are suitable to digest in HLAD process.

It is known, the cow and piggery farms – also other animal farms – produce besides of their main business also side products like manure. In normal run, it is possible to utilize back in the fields, but not immediately. Before utilization the manure needs stabilization time and the problem will rise because of quite long retention time. Big volumes need also big storages which require costs.

One way is to stabilize faster the manure. We know that the composting requires long time – mostly several months and also other matters and quite big storage areas. Composting consumes energy and additionally the amount of the end product is even higher.

Digestion

Digestion is sophisticated method – producing biogas energy and quite fast also stable matter for recycling it back in the fields. Quite big argument is also that the end volume will be reduced even to 50% being also easy handling solid matter. Big advantage is that the nutrients of nitrogen and phosphorous will remain in the solid end product.

The cow and piggery houses produce solid manure but also urine together. This composition is yet quite dry.
But nowadays the animal houses are cleaned more or less by wash waters and the waters are led in same basin where the manure is transferred. We are talking about manure sludge having dry solids from 5% to 10%, fluctuating case by case.

The digestion methods are several ways. There is a conventional method – digesting as very thin slurry, DS being less than 5%. There are dryer methods – digesting as thicker slurry, DS being however less than 10%. Liquid part in the mixture is urine water which does not produce just now biogas.

One sophisticated way is to digest dryer manure using HLAD (high loaded anaerobic digestion) process. It is processed by the substrate feed of more than 15 %DS.
The volume difference between 5 %DS and 15 %DS is threefold. It is quite huge difference of bioreactor volume when thinking about 20 day's retention time in the manure digestion. It means essentially smaller bioreactor volume – and also more smooth investment.

But how to operate by this way in farm or in the farms? The manure slurry spreading is not so clean. There are often also some equipment troubles in the spreading – blockings and also high smelling harms. Stored manure is never non-smelling despite of longer storage retention time.

Also the manure is yet more or less very thin using in this kind high digestion volume.

Winning Idea

The winning idea is to dewater – calling also to separate - the manure slurry first. When separating the results are urine water and solid cake. Dry solid content of the cake may rise even to 20 %DS.

As dryer the cake is, as more is urine water volume and it is very easy and faster to spread in the field. Urine water is excellent fertilizer with high nitrogen content. The surplus nitrogen is more useful in the field than in the digestion process. Too high nitrogen amount is not allowed in the digestion. That is big argument especially for piggery manure digestion.

The hose spreading is very sophisticated and easy way for liquid spreading.

The remained cake will be digested using HLAD process after adjusting to 15 %DS and mesophilic temperature of 37 ^{o}C. The feed solid content of 15-20 %DS in the feed is optimal and it is considered case by case.

After digestate outlet it will be dewatered upto 30 %DS cake. Produced reject water is again very excellent for field fertilizing – without any solids. The excellence is again high nitrogen content as ammonia what is very easy to be utilized by the plants.

Second argument is also that the produced cake includes most of the manure phosphor and its utilization is considered according to the phosphor demand in the field. The cake is excellently utilizable also for greenhouses or other soil improvement.

This method application is very simple and excellent way to manage farm manures by environmental and cost effective way.

The Economy

But how to realize this kind of procedure economically? We know that the farmers are very careful against the costs. Also one big revenue is lacking having in waste treatment plants – a gate fee.

Best solution is to treat enough big volumes of manure – needing enough big farm or farms. The biogas energy and fertilizer begin to become more or less cost-effective.

The 10 tons of dry solids per day are some kind of the limit for economical operation.

Mostly this means consortium of enough many farms. Because shared manure treatment is possible – shared farm equipment is not. The grain crop is maturing same time and the harvest needs individual equipment for that.

Although enough big AD plant is not gold mine, it should be enough that the AD plant will be as minimum an economically neutral solution but also environmentally solid solution. The farmer can however try business when receiving manure also with small gate fee. It can regulate the annual profit remarkably.

But this all requires right technology - like HLAD process method is.

Economy Examples

It can be presented two alternative case where can be seen economical influence of manure amount.

The case 1 is 10 tons dry solids per day. It means about 3 650 tons DS per year and about 52 100 m^3/a manure slurry as 7 %DS.

The case 2 is 30 tons dry solids per day. It means about 10 950 tons DS per year and about 156 400 m^3/a manure slurry as 7 %DS.

Case 1:

10	**tDS/d**
3 650	tDS/a
3 103	tVS/a
1 396 125	m³/a
9 075	MWh/a
1 700	m³ bioreactor
7 908	t/a end product as 30 %DS

Digestion Plant, Cow Manure

Investment			**1 800 000**	**EUR**
- Capital Cost (10 y., 8%)			268 200	
- Operation Cost (fixed & variable)			108 000	
- Maintenance & Prepair Costs			40 500	
Annual Cost			**416 700**	**EUR/a**
Annual Revenue			**512 993**	**EUR/a**
- Biogas energy	40	EUR / MWl	362 993	
- Fertilizer	500	EUR / t of N	150 000	
Annual Profit			**96 293**	**EUR/a**
Payback time			**18,7**	**years**

Case 2:

30	**tDS/d**
10 950	tDS/a
156 429	t/a
9 308	tVS/a
4 188 375	m³/a
27 224	MWh/a
5 100	m³ bioreactor
23 725	t/a end product as 30 %DS

Digestion Plant, Cow Manure

Investment			**3 000 000**	**EUR**
- Capital Cost (10 y., 8%)			447 000	
- Operation Cost (fixed & variable)			180 000	
- Maintenance & Prepair Costs			67 500	
Annual Cost			**694 500**	**EUR/a**
Annual Revenue			**1 563 478**	**EUR/a**
- Biogas energy	40	EUR / MWl	1 088 978	
- Fertilizer	500	EUR / t of N	474 500	
Annual Profit			**868 978**	**EUR/a**
Payback time			**3,5**	**years**

TECHNICAL MODIFICATIONS AND CONCEPTS FOR CONTROLLABLE ELECTRICITY PRODUCTION VIA BIOGAS PLANTS IN GERMANY

Häring G.; Sonnleitner M.*; Zörner W.*; Hanby V.**; Bichlmeier S.****
**CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH, Ingolstadt University of Applied Sciences*
Esplanade 10, D-85049 Ingolstadt, Tel.: +49 841-9348 641, Fax: +49 841-9348 644
E-Mail: georg.haering@haw-ingolstadt.de, Internet: www.haw-ingolstadt.de
***Institute of Energy and Sustainable Development, De Montfort University, Leicester (UK)*
****UTS Biogastechnik GmbH, Zeppelinstraße 8, 85399 Hallbergmoos*

ABSTRACT: With the expansion of renewable but fluctuating power generation from wind and solar energy, the demand placed on the security and reliability of electricity supply is increasing. To ensure grid stability in the future, controllable power production via biogas plants has a great technical and economic potential.

In this context, the *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH* at *Ingolstadt University of Applied Sciences* and the biogas plant manufacturer *UTS Biogastechnik GmbH*, Hallbergmoos, Germany, are working on the research project "BioStrom – Controllable Electricity Production via Biogas Plants", funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

This paper describes first results regarding technical modifications for a controllable electricity production via biogas plants. Furthermore, the operational mode of CHP-Units in accordance with the demand of the electricity grid and achievable additional revenues are shown by taking the limited gas storage volume into account.

KEYWORDS: biogas, controlled electricity production, gas storage

1. INTRODUCTION

In the year 2010, 52 GW of the total 135 GW installed power generation capacities in Germany were based on renewable energies. The major part of the renewable electricity production (wind-onshore, wind-offshore, PV), however, produces not on demand but fluctuating electricity. By 2020, the ratio will be inverted. At this point, the power generation capacity of renewable energies will be more than twice that of conventional power plants. This evolution will continue in the years ahead [1].

This situation leads to several challenges which have to be faced. In times when the conventional power plants dominate, the fluctuating electricity production from wind energy and photovoltaic can be compensated easily. In the near future, the installed power generation capacities from renewable energies will exceed the ability of the conventional power plants to compensate the fluctuating electricity production. This will lead to a lack or a surplus of electricity in the grid. Thus, several wind turbines already had to be shut down in Germany temporarily, because the power generation from wind during times of high wind exceeded the capacity of the grid to absorb these high amounts of electricity.

Currently, the electricity production in Germany is only on demand. Due to a rising amount of fluctuating renewable electricity producers, the electricity production will be carried out primarily on its availability in the near future. This means, the production of electricity is not congruent with the demand and there will be periods with a lack or with a surplus of electricity in the grid.

During times of underproduction additional electricity capacities are needed; during periods of overproduction the surplus of electricity must be stored for periods of underproduction. To ensure grid stability in the future, potentials in the fields of load management and new storage technologies have to be developed.

Biogas has the ability to be stored among the renewable energies and a higher efficiency can be achieved for the storage of electricity in comparison to pumped-storage hydroelectricity, compressed-air energy storage or in the form of hydrogen. Therefore, the controllable power production from biogas has a high technical and economic potential.

This paper describes results regarding technical modifications for biogas plants with a controllable electricity production. Furthermore, the operational mode of CHP-Units in accordance with the demand of the electricity grid and achievable additional revenues are shown by taking the limited gas storage into account.

2. INCENTIVES FOR A CONTROLLABLE ELECTRICITY PRODUCTION VIA BIOGAS IN GERMANY

The German Renewable Energies Acts (EEG) 2004 and 2009 did not give any incentives for biogas plant operators to produce electricity on demand. This was due to subsidies considering only the amount of electricity, and not the period during which electricity is fed into the grid.

Thus, an economic benefit can be achieved only by operating biogas plants with very high CHP usage rates and full load hours. For this reason, conventional biogas plants are currently operated continuously and at a high rate of full load hours. However, this mode of operation is not in compliance with the requirements of the electricity grid.

With the EEG 2012, operators of biogas plants are incited to produce electricity on demand. Now, legislative changes enable biogas plant operators to leave the EEG with the possibility to turn back into the EEG-model with fixed feed-in tariffs at a later date. Thus, operators can choose at any time to place the electricity produced on the market or to get subsidies from the EEG.

These legislative modifications imply the introduction of three premiums to make the placement of electricity on the market attractive and compensate for the investment for additional plant equipment for a demand-driven electricity production. These three premiums are the Market Premium, the Management Premium and the Flexible Premium.

2.1 Market Premium

The Market Premium is intended to cover the market price risk.

The amount of the market premium is calculated by the difference of the monthly average price on the day ahead spot market of the EPEX SPOT SE and the fixed EEG feed-in tariff.

2.2 Management Premium

The Management Premium is intended to cover the marketing efforts. In 2013, the Management Premium is EUR 0.00275 per kWh.

2.3 Flexible Premium

The Flexible Premium is intended to cover the investment for additional plant equipment such as higher power generation capacity and additional gas storage necessary for the flexible and controlled electricity production.

The amount of the premium is EUR 130 per year for each additional installed kW_{el}. The premium is paid for 10 years.

3. PROJECT "BIOSTROM – CONTROLLABLE ELECTRICITY PRODUCTION VIA BIOGAS PLANTS"

The controllable electricity production via biogas plants depends on various factors. Besides the stability of the biological process, cost is the main issue. To achieve an economic optimum, efficient control strategies and system configurations must be chosen. These are currently not fully known, thus, further research is necessary.

In this context the *Centre of Excellence for Renewable Energy Research* at *Ingolstadt University of Applied Sciences* is currently working on the research project "BioStrom – Controllable Electricity Production via Biogas Plants", funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

The aim of the project is the creation of a new area of application for biogas by enabling existing biogas plants to act as controllable electricity producers. Initially, a variety of approaches to transform existing biogas plants into controllable electricity producers are defined. In cooperation with the biogas plant manufacturer *UTS Biogastechnik GmbH*, Hallbergmoos, Germany, the favourable modification concept is then selected and implemented on an existing biogas plant.

4. OPERATING SCHEDULE FOR FLEXIBLE ELECTRICITY PRODUCTION

For the flexible electricity production, biogas plants have to act in accordance with the demand of the electricity grid. The most important instrument for this purpose in Germany is the electricity market, in particular the Day Ahead Auction of the EPEX SPOT SE. The EPEX SPOT is an European market place for electricity. This market also determines the amount of the market premium within the EEG 2012. Figure 1 shows the average hourly electricity price of the Day Ahead Spotmarket in Germany/Austria of 2011.

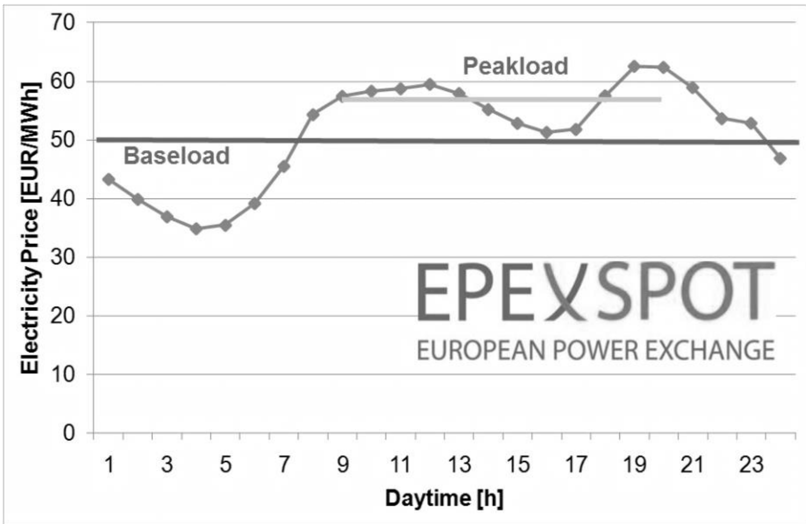


Figure 1. Average Hourly Electricity Price 2011

The prices of the Day Ahead Auction are determined by supply and demand for each hour of the following day. Thus, plants which are operating to this price signal are operating in accordance to the demand of the electricity grid.

This way higher revenues in comparison to the base load-operation can be achieved by shifting the electricity production from low-price periods (during the night and lunch time) to high price periods (morning and evening).

In order to vary the electricity production, higher generation capacities as required for a base load-operation, have to be installed. Additionally, the biogas plants must be able to shift the utilisation of the biogas. I.e. the plants must be able to provide the gas at high-priced times. A time based operational schedule can be implemented in the internal control system.

Many biogas plants are suitable for a flexible electricity production. By using biogas storages, the biogas production can be decoupled from the power generation. So the schedule for the feeding management does not have to be changed significantly. With these technical pre-requisitions the required amount of biogas can be adapted to the demand of the electricity grid.

To produce as much electricity as possible during times of high prices at the electricity market, the temporary stored amount of biogas has to be utilised with higher electrical power capacities and during shorter operating periods than in base load-operation.

This leads to new requirements for the components of the gas storage, gas processing, gas utilisation and heat utilisation.

5. DEMAND ORIENTED GAS PROVISION THROUGH TEMPORARY GAS STORAGE

A temporary storage of biogas in biogas plants gas storage facilities gives the possibility to decouple the gas production from the gas utilisation.

For the flexible electricity production existing gas storage technologies can be used. The most common way of storing biogas is in the gastight coverings of digesters and residue storage tanks. The average storage capacity of biogas plants in Germany is about 25 % of the daily produced amount of biogas [2].

Gasholders are currently intended to compensate a fluctuating biogas production and to store the produced biogas during planned and non-planned maintenance. For this application neither the gas storage capacity nor the accuracy of the fill level monitoring are that important.

In the case of a demand oriented electricity production the available actual usable gas storage volume (lung-volume), the accuracy of the fill level monitoring and the possibility of the combination of several gasholders to increase the total lung-volume (gas storage management) are very relevant.

The size of the necessary storage volume for a flexible electricity production depends primarily on the overall system concept of the biogas plant. If the plant has already sufficient gas storage volume, electricity can be produced flexible by increasing the electrical power capacities. The following applies: Not the operating schedule determines the required gas storage volume, but the volume of the gas storage and the installed capacity determine the operating schedule.

5.1 Evaluation of different gas storage technologies

Very important for the controllable electricity production via biogas plants is the suitability of gas storage technologies. Important factors for the storage of biogas are the usable volume, the monitoring of the gas storage fill level and its ability for gas storage management.

Table 1. Evaluation of different gas storage technologies

Gas Storage Technology	Usable Volume	Fill Level Monitoring	Gas Storage Management
Single Membrane Systems (EPDM)	**0**	**0**	**-**
Double Layer Systems	**0**	**0**	**-**
Air Supported Systems	++	+	+++
Membrane Gas Reservoirs	+	**0**	+

The usable volume of **single membrane systems made of ethylene propylene diene monomer (EPDM)** is limited by the expansion of the membrane. For the static of the covering the pressure inside the single membrane system should not be too low. Due to many influencing environmental factors such as solar radiation on the membrane, the monitoring of the fill level is difficult and not accurately possible. Also an active gas storage management in not possible by using this storage technology.

In **double layer systems**, the tanks are covered with two membranes, which are supported by a pillar in the middle of the tank. The outer membrane protects the inner membrane from the weather. The actual gas storage takes place under the inner membrane. The usable gas storage volume of this technology is rather low. An accurate fill level management and gas storage management is not possible.

The usable volume of **air supported double layer systems** is only limited by the outer membrane and the substructure. Due to this reason its usable volume is high. The pressure of those systems can be adjusted easily. In contrast to other gas storage technologies the fill level of air supported double layer systems can be monitored quite well. By adjusting the supporting air a gas storage management can be also realised.

Theoretically **membrane gas reservoirs** can also be integrated as the last element of the pressure cascade.

As the comparison shows, air supported double layer systems are most suitable for the controlled electricity production via biogas plants. They enable the largest usable storage volumes and the most accurate fill level measurement.

5.2 Gas Storage Management

The gas storage management is very important for the controllable electricity production via biogas plants. In contrast to a continuous biogas production, electricity is produced discontinuously. Due to this reason the gas storage is filled and deflated.

To produce electricity on demand the produced amount of biogas, the stored amount of biogas and the demand for biogas for the CHP-Unit(s) have to be known at any time.

Aim of the gas storage management is the monitoring and control of several gas storages.

It is recommended to store most of the biogas near the CHP-Units. So a reliable and sufficient amount of biogas is available and can be used for a controlled electricity production.

For this reason a pressure cascade has to be created. In this pressure cascade the lowest system pressure should be at the gas storage which is nearest to the CHP-Units.

5.2.1 Standardisation of the Gas Volume

For the operation and control of the demand oriented electricity production via biogas plants the recording of the available amount of biogas and its energy quantity is very important. Since the volume of gases depends on temperature and pressure, it is necessary to refer the volumes to standard conditions. So a comparison of biogas yields, volumes and stored amounts of energy can be carried out.

For dry gases, the standard volume can be calculated according to the following formula 1:

$$V_s = \frac{V \times T_N \times p_G}{T \times p_N} \qquad (1)$$

with: V_S = standard volume of the gas [Nm³]
V = actual volume [m³]
T = temperature of the gas [K]
T_S = standard temperature (273.15 K)
p_G = absolute pressure of dry gas [bar]
p_N = standard pressure (1.01325 bar)

Since in internal gas storages, the biogas is usually saturated with water vapour, the water content of the biogas must be considered in order to determine the stored amount of energy. For this purpose, the absolute pressure of the gas storage has to be reduced by the partial pressure of the dry biogas (formula 2).

$$p_G = p_{abs} - \varphi \times p_S \qquad (2)$$

with: p_{abs} = absolute pressure in the gas storage [bar]
φ = relative humidity in the biogas [%]
p_S = partial pressure of water vapour [bar]

According to formula 1, the gas temperature has a significant influence on the storable standardised volume. The gas temperature in the gas storage depends on several factors such as the ambient temperature, the type of digester where the gas storage is located (heated or non-heated digesters) and how the solar radiation affects the gas storage. Double layer gas storages minimise the ambient influences and bright outer membranes can reduce the influence of the solar radiation.

5.2.2 Fill Level Measurement for Gas Storages

For the record of the stored amount of energy in gas storages the composition, the temperature, the pressure and the volume of the stored biogas have to be known.

As described in chapter 5.1 air supported double layer systems are most suitable for the controlled electricity production via biogas plants. Therefore, the fill level monitoring technologies for this gas storage technology are discussed.

In air supported double layer gas storages the fill level measurement takes place via measurement of the position of the inner membrane.

Since the pressure in the gas storage and the space between the inner and outer membrane (supporting air space) are almost identical, the inner membrane is moulded irregular, depending on the gas streams in the storage space and the supporting air space. These characteristics regarding the position of the inner membrane cause considerable challenges for fill level measurement systems. So different technologies for the fill level monitoring are discussed and assessed.

Non-Contact Systems (Ultrasonic)

Non-contact systems, which measure the distance between inner and outer membrane via an ultrasonic signal are usually not used for digester-mounted air supported double layer systems. The reason for this is, that the inner membrane supplies no defined reflection point for the ultrasonic signal.

For ¾ spherical shape air supported double layer systems this technology can be used, since the inner membrane can be designed in the way that it moulds in a defined manner.

Rope Systems

Rope systems measure the position of the inner membrane by using a rope which is stretched over the inner membrane. The rope is finally put through the outer membrane and ends over deflection rollers in a measuring tube. Each change of the inner membrane position leads to a length variation of the rope in the measuring tube. At the end of the rope is a magnet, which operates the reed switches in the measuring tube.

The accuracy and reliability of this measurement method is low, since the membrane can sag under the stretched rope or bulges next to the rope cannot be detected. Another weakness is the low resolution of the signals which are produced by the reed switches.

This measuring system is also very susceptible to failure due to its mechanical design. For example the rope can get stuck. This way the results can become unusable for the gas storage management.

Water Level Gauge Systems

State-of-the-art fill level monitoring systems for air supported double layer systems are water level gauge systems.

A fluid-filled tube is fixed at a defined position of the inner membrane. When the inner membrane position is changing, the hydrostatic pressure at the opposite end of the tube alternates. This change in hydrostatic pressure is measured and the position of the defined measuring point can be detected.

A major benefit of this system is that several tube scale systems can be installed at the inner membrane. This allows a good consideration of the membrane moulding. In comparison to other measurement methods, most reliable results can be achieved with hydrostatic tube scale systems.

6. FLEXIBLE BIOGAS UTILISATION

A flexible biogas utilisation can be achieved in two different ways. One option is the intermitting operation of CHP-Units at its nominal load, the second option is the part load operation of CHP-Units.

Present engines of biogas CHP-Units are highly developed and optimised for an operation with biogas. Conventional CHP-Units in Germany are, due to the previous funding structure (renewable energies acts of the years 2000, 2004 and 2009), adapted to a base load-operation and optimised for a high number of full load hours.

6.1 Intermitting Operation

CHP-Units with combustion engines are well suited for an intermitting operation. They can be kept permanently on standby and allow fast response times. The intermitting operation can be carried out according to a defined operating schedule at specific times, on short-term price signals or short-term needs.

A start–stop-operation causes higher material stress to the CHP-Units than a nominal operation. At nominal load, the engine operates in its optimum range and has the highest efficiency and minimal wear. During combustion high temperatures arise in the combustion chamber, which lead to stress for the engine-components. In nominal load operation stable operating conditions are reached. The parts, components and also the lubrication are designed for these stable conditions. During the start the components are still cold and the necessary lubrication to minimise friction does not exist. With the beginning of the combustion the materials are exposed to high temperatures. At the start components such as cylinders, cylinder heads, pistons and the exhaust system are stressed with temperature differences, which lead to tensions in the materials and different gaps between the parts. This leads to friction, which is increased due to an insufficient lubrication at the beginning of the start.

To achieve a high service life and operating safety of the CHP-Units the minimum runtime per start and maintenance schedules must be in compliance with the CHP-manufacturers` recommendations.

6.1.1 Auxiliary Equipment for a reliable Start of CHP-Units

Important auxiliary equipment to achieve a long service life and reliable starts with an intermitting operation of CHP-Units are pre-heating and pre-lubrication of the engine. In many modern CHP-Units these devices are already used. Auxiliary equipment lowers resistances during the start and leads to better combustion-conditions [3].

Pre-Heating

The pre-heating of the engine is an effective way to minimise stress during the start.

The engine components and the lubricant are heated up to a temperature of about 56…60 °C before it starts [4]. This is done to ensure a proper viscosity of the lubricant and to avoid temperature differences among the engine components. The cooling water circuit of the CHP-Unit is used for this [5].

Additional equipment is the installation of a heat source, components for the cooling water circuit (ability to use this circuit for heating as well) and the integration of the components into the engine control unit. One heating source can be heating rods, embedded in the cooling circuit. Heating storages in the heating circuit of the biogas plant or the process heat can also be used as heat sources. Existing engines can be retrofitted easily. Compared to the overall investment for a CHP-Unit the costs of an additional pre-heating are low.

Pre-Lubrication

A further auxiliary equipment is the pre-lubrication. An electric pump (separate oil pump or an additional one parallel to the main oil pump) ensures the necessary oil pressure before the engine starts. So an oil film can be formed. This way mixed friction is avoided. A post-lubrication is also recommended to lubricate running components such as the turbocharger after the shutdown. Also a slow cooling of hot components can be ensured [4].

The required capacity of the pump depends on the size of the CHP-Unit. According to manufacturers, the power consumption of oil pumps can be between 2 and 5 kW_{el}. CHP-Units up to 500 kW_{el} usually do not need any pre-lubrication, according to manufacturers` information.

6.1.2 Starter Systems

Frequent starts cause higher stress for the starter components of the CHP-Units. A reliable start can be achieved by providing high starting speeds [3].

Usually battery powered starter systems are used. As an alternative grid driven starter systems can be used. In this case, the engine is started by utilising the power from the electricity grid. The advantage of such systems is a higher starting speed of about 20 % in comparison to battery powered systems [3].

6.1.3 Condensation due to Intermitting Operation

Higher amounts of condensate can occur due to the intermitting operation of CHP-Units. Frequent cold starts and the resulting hot gases get in contact with cold component surfaces and lead to this higher amount of condensate.

If the engine starts pre-heated, the amount of condensate is reduced. The condensate must be removed via suitable condensate traps to avoid corrosion and other defects.

6.2 Part Load-Operation of CHP-Units

Another option for the flexible production of electricity is the part load-operation of CHP-Units. The advantage compared to the intermitting operation at nominal load is that the flexibility can be reached without additional start processes. In general biogas CHP-Units can be operated with up to 40 % of their nominal load.

The engine is not running in its optimum conditions, which finally leads to additional stress. Auxiliary drive systems, the cooling circuit and the lubricant circuit are designed for the nominal load. With the part load operation, pumps and turbochargers no longer work at their optimal operating point. This causes increased lubricant consumption and auxiliary energy demand.

As the reduced exhaust gas volume flow is cooled faster as compared to the base load-operation, the part load-operation is associated with a larger amount of condensate.

Also the combustion of the fuel-air mixture is no longer in an optimal range. The engine is exposed to higher stress due to unburned components of the gas mixture [6].

To avoid too high mechanical stress, manufacturers recommend maximal part loads of 40...50 % of the nominal load.

In summary part load-operation leads to an increased engine stress and to a lower efficiency in the biogas utilisation.

Figure 2 shows the efficiency curve of an exemplary CHP-Unit in part load-operation. The CHP-Unit has a lower efficiency in the part load range. A significant increase in efficiency losses already takes place at part loads of 85 %. In practice, even higher efficiency losses are assumed, which can vary between 1 and 2 percentage points [6].

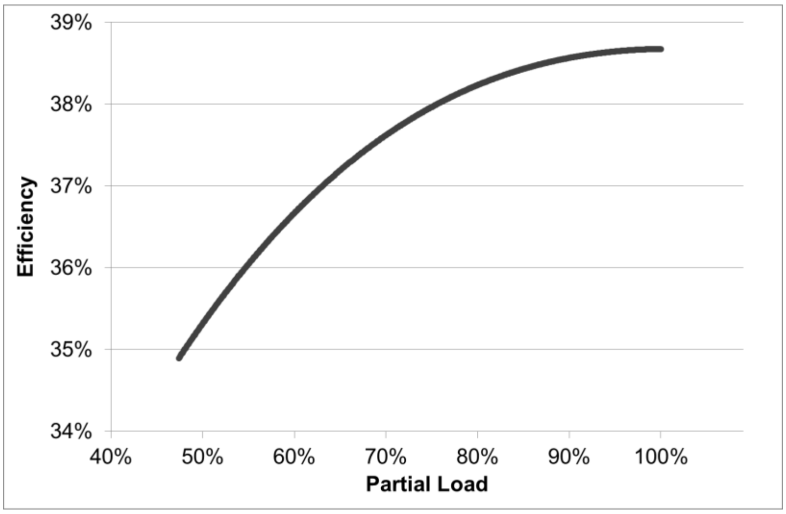


Figure 2. Efficiency Characteristic Curve of a CHP-Unit [7]

From about 90 % part load, the intermitting operation at nominal load is the more energy efficient operation mode for a biogas plant [6].

High part load-operating times increase the risk of losing additional electricity market revenues due to the inefficient utilisation of the biogas and the higher demand for substrates.

It can be assumed that the CHP-Unit in part load-operation is lower stressed than in an intermitting operation. But an intermitting operation the CHP-Unit needs a shorter operating time to produce the same amount of electricity as a part-load operation. For this reason, a longer service life in years of the CHP-Unit in intermitting operation can be assumed.

Nevertheless, situations can arise in which the part load-operation seems quite interesting for biogas plants. These situations can be for example starting problems due to short-term biological problems. Especially the heat supply of the biogas plant or external customers can be an important argument for the part load-operation.

6.3 Gas Conditioning

For the controlled electricity production, the gas conditioning as well as the gas supply system have to be designed for the gas flow at maximum power production.

Due to the adverse conditions for the CHP-Units, associated with the flexible operation, the CHP-Units are higher affected by high water and hydrogen sulphide contents as in base load-operation. For this reason, the quality of the gas conditioning system has to be adapted to the changed conditions.

6.4 Heat Supply

In biogas plants the produced heat is needed to maintain the fermentation process. The fermentation requires a constant temperature level. Depending on the heat losses of the digester its thermal energy demand varies. Currently, the heat supply is ensured by the base load-operation of the CHP-Units. Failure in heat supply due to short-term maintenance or interruptions can be buffered by the heat which is buffered in the digesters.

The heat demand for heating the digester depends on many factors and is highly plant-specific. In addition to the temperature level of the digestion-process and the used substrates, the residence time influences the heating demand as well. Also the structural design of the digester is important. For example, the heat insulation of double layer digester-covers is much better than the heat insulation of single layer digester-covers.

In general, digesters of biogas plants are well insulated and the masses are sufficiently large. So the substrate temperature does not drop significantly in the digesters during a few hours lasting CHP-Unit failure.

To ensure the heat supply of the digesters, the plant-specific heat losses have to be taken into account, when designing the operating schedules for a flexible electricity production.

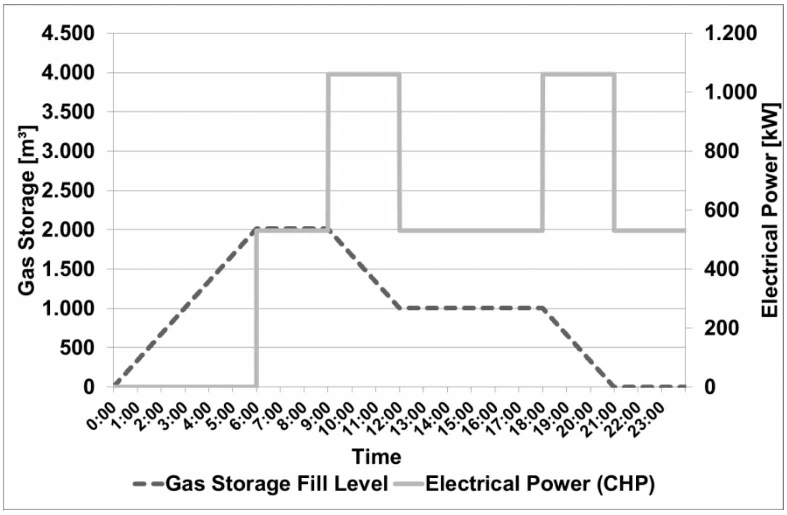
The heat supply can also be buffered by using heat storages. So a constant substrate temperature can be ensured. With appropriately sized heat storages it is also possible to produce electricity on demand and to ensure the heat supply of external consumers at the same time.

By installing additional electricity production capacities and heat storage capacities, the benefit of additional redundancy is created. The flexibility of the system or the operating schedules can also be varied and adapted during the year according to the annual load duration curve of the heat utilisation concepts.

7. CONCEPT EXAMPLES

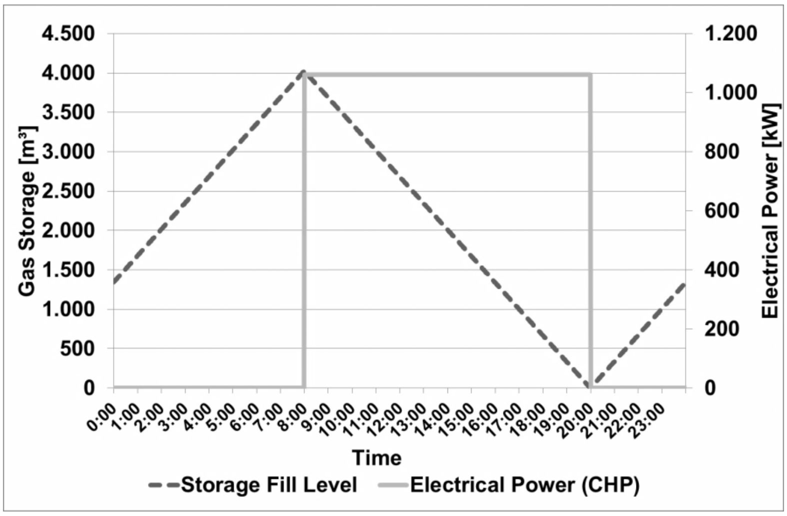
Figure 3 and Figure 4 show examples for the operating schedules of an exemplary biogas plant. The average electric capacity of the shown biogas plant is 500 kW.

Figure 3 shows an operating schedule, optimised for the hourly price signal of the power exchange (see Figure 1) and the plants existing available usable gas storage volume of 2,000 m³. According to this schedule, one CHP-Unit is put into operation from 6 am to 12 pm. The second CHP-Unit is switched on from 9 am to 12 am and from 6 pm to 9 pm. With this operational schedule no additional gas storage is necessary. The maximum shift of the electricity production is 6 hours. With this operating schedule the feasible additional revenue at the electricity market, in comparison to the base load-operation, is 26.660 € per year.



max. shift of electricity production: **6 h**
feasible additional revenue*: **26,660 €/a**
*assumptions: *EPEX Spot* average value 2011;
Management premium (EEG 2012): 0,00275 €/kWh_{el} (2013);
Profit sharing for electricity trader: 30 %

Figure 3. Operating Schedule without Additional Gas Storage



max. shift of electricity production: **12 h**
feasible additional revenue*: **28,420 €/a**
*assumptions: *EPEX Spot* average value 2011;
Management premium (EEG 2012): 0,00275 €/kWh_{el} (2013);
Profit sharing for electricity trader: 30 %

Figure 4. Operating Schedule with Additional Gas Storage

In comparison to this, Figure 4 shows a second scenario. It is an operating schedule where both CHP-Units are running from 8 am to 8 pm. So the maximum shift of the electricity production is 12 hours. The necessary gas storage volume for this operational mode is 4,000 m³. This means an additional gas storage of 2,000 m³ and further investments. The feasible additional revenue at the electricity market with this operational mode is 28,420 € per year, only 1,760 € more than in the first scenario.

This shows that an intelligent operating schedule can gain a good additional revenue at the electricity market and can avoid additional investments in further infrastructure.

8. CONCLUSIONS

Biogas will be a key technology within the renewable energies in the future, since only biogas has the ability to be stored and to produce electricity on demand. So biogas will produce high-quality electricity when it is needed, instead of base load electricity as in most cases today.

The changed requirements associated with the controllable and flexible operation of biogas plants for the components of the gas storage, gas processing, gas utilisation and heat utilisation can already be met with the available technology.

Biogas plants with additional installed capacities should use the opportunity to produce electricity on demand to achieve additional revenues. Thereby, any biogas plant has a specific flexibility and specific possibilities for the design of demand oriented operation schedules.

9. REFERENCES

[1] SACHVERSTÄNDIGENRAT FÜR UMWELT-FRAGEN (Ed.) (2010) *100% erneuerbare Stromversorgung bis 2050: klimaverträglich, sicher, bezahlbar*. Berlin: Sachverständigenrat für Umweltfragen.

[2] FACHAGENTUR NACHWACHSENDE ROHSTOFFE e.V. (Ed.) (2009) *Biogas-Messprogramm II 61 – Biogasanlagen im Vergleich.* Gülzow: Fachagentur Nachwachsende Rohstoffe e.V. (FNR).

[3] VAN BASSHUYSEN, R. and SCHÄFER, F. (2004) *Lexikon Motorentechnik.* 1. Edition, Wiesbaden: Vieweg Verlag.

[4] GE JENBACHER (Ed.) (2012) *Technische Beschreibung BHKW JMS 312 GS-B.L.* Jenbach (Austria): GE Jenbacher GmbH & Co OG.

[5] ZACHARIAS, F. (2001) *Gasmotoren*. 1. Edition, Würzburg: Vogel.

[6] JUNG, U. UND MÜLLER, R. (2008) Teillast oder Takten?. *BWK Das Energie-Fachmagazin,* Ausgabe 6/2008 Seiten 45-47.

[7] 2G ENERGIETECHNIK (2011) *Planungsdaten 2G-KWK-190BG/50 Hz.* Version 1.3, Heek: 2G Energietechnik GmbH.

PRODUCTION AND CHARACTERIZATION OF BIOCRUDE FROM BIOGASIFICATION AND SEWAGE SLUDGES

Assoc. Prof. Dr. Haydar Livatyalı, TÜBİTAK MAM, Başuzman Araştırmacı , PK.21 41470 Gebze Kocaeli TURKEY, e-mail: mehmet.unsal@tubitak.gov.tr, Tel: +90-262 677 2824
Dr. Mehmet Ünsal, TÜBİTAK MAM, Uzman Araştırmacı, PK.2141470 Gebze Kocaeli TURKEY, e-mail: mehmet.unsal@tubitak.gov.tr, Tel: +90-262 677 2952
Dr. Parvana Aksoy, TÜBİTAK MAM, Uzman Araştırmacı, PK.21 41470 Gebze Kocaeli TURKEY, e-mail: parvana.aksoy@tubitak.gov.tr , Tel: +90-262 677 2783
H. Alper Önoğlu, Altaca Çevre Tekn. ve Enerji Üretim A.Ş. GOSB Teknopark, Gebze, Kocaeli TURKEY, e-mail: alperonoglu@altaca.com, Tel: +90 262 678 8840
Prof. Dr. A.Erhan Aksoylu, Bosphorous University, Bebek 34342İstanbul TURKEY e-mail: bedirhas@boun.edu.tr Tel: +90-212 359 7362
Assoc. Prof. Dr. Hasan Bedir, Assoc. Prof. Dr. Hasan Bedir, Bosphorous University, Bebek 34342İstanbul TURKEY, e-mail: aksoylu@boun.edu.tr, Tel: +90-212 359 7216

"Altaca Oil" is a 3rd generation renewable biofuel synthesized from wet biowaste containing mixtures of lignocelluloses, proteins, fats and carbohydrates using an innovative hydrothermal conversion process named as the CatLiq® (Catalytic Liquidification) Process. The CatLiq process is an aqueous catalytic hydrothermal liquefaction process that takes place at supercritical conditions in the range of 230-250 bar and 350-400^{o}C and the product is called as Altaca oil. Altaca Oil is a unique product that meets the specifications of both biofuels and biocrudes. Moreover, with a mixture proportion of 1-3% of crude oil, Altaca oil can be subjected to refining or it can be used directly as a fuel for generating heat. Under the conditions that petroleum and by-products stick to the current market prices, it is an economically feasible and environmentally friendly alternative with the waste treatment features, carbon neutral, fertilizer additive by-products and no hazardous output to the environment.

Chemical compositions of the Altaca oil vary according to the selected feedstock and the process conditions. Altaca Oil has higher nitrogenated and oxygenated groups such as amine, hydroxy, carbonil and carboxyl than fossil-based fuels. Therefore, in spite of a relatively higher specific gravity and viscosity, it contains mostly light and middle carbon chain fractions in the C5 - C12 range and the calorific value reaches 33-39 MJ/kg. Because of these properties, analysis of this oil with the API crude oil standards and comparison of its results with conventional petroleum based fuels gives misleading results. In addition, Altaca oil contains mostly less than 5% of water and 1% sulfurous contaminants (by weight). Being a wet process that does not require drying and the effective homogenous and heterogeneous catalyst composition, the mass conversion ratio is relatively high and the energy consumption is relatively small. With these properties, Altaca oil is a strong alternative to other second and third generation biofuels such as the pyrolysis oil and Fischer-Tropsch oils.

In the development phase of the CatLiq process, after the bench scale laboratory tests, a laboratory scale and a small demo scale pilot plants have been designed, built and tested. The upgraded version of the lab pilot plant is currently operational in Gebze-Kocaeli, Turkey and a series of tests have been conducted to optimize conversion conditions of biogasification and sewage sludges as well as DDGS, bagasse, wheat and rice straws, city garbage, paper mill waste treatment sludge and some forest by-products. The characterization efforts and experimental results for the biogasification and sewage sludges shall be presented in the conference.

Altaca Energy has been running a pilot plant since 2011 on its premises in Turkey. The pilot plant has provided valuable experience about process capabilities and optimization as well as potential feedstock materials. Pre-commercial demonstration plant is underway at the Gönen, Balikesir. The demonstration plant project is partly funded by TUBITAK TEYDEB. The aim of this project is design and construction of demo plant, and completion of all certification procedures for commercialization of CatLiq® oil.

Two types of oils synthesized from biogasification and sewage sludges were characterized using several analysis methods; among them are elemental analysis and GC-MS. The study shows that both feedstocks can be converted to bio oil with high yields. The results also indicate that the boiling point of oils are significantly low and possibly can be used as a transportation fuel after further optimization. These results have been taken as basis to design of the demonstration plant that shall be commissioned in early 2014.

REMOVAL OF CO_2 FROM BIOGAS BY CONCENTRATION SWING ADSORPTION USING POLYMER RESINS

K. Raab, B. Heidel, G. Scheffknecht
University of Stuttgart, Institute of Combustion and Power Plant Technology (IFK),
IFK, Pfaffenwaldring 23, D-70569 Stuttgart, Germany
katharina.raab@ifk.uni-stuttgart.de

ABSTRACT

The considered process uses polymer resins, which adsorb CO_2 from gases and can be regenerated by purging with air. This concentration swing adsorption process could be used for the upgrading of biogas to biomethane. The high quality of the product gas enables its injection into the natural gas grid. In adsorption experiments, the ability of the resin to adsorb CO_2 from gas streams was shown and CO_2-desorption was successfully carried out by purging the resin with air. Using results of equilibrium loading experiments at different partial pressures and temperatures, adsorption isotherms were established. Continuous experiments were carried out with the lab-scale plant consisting of two columns interconnected with magnetic valves. Working capacities for different temperatures and purging gas streams were determined. With lower temperatures higher working capacities were achieved for the examined resin, especially with high purging gas streams. The energy balance showed the influence of thermal and electrical energy demand and of the methane loss caused by column switching. The lowest energy loss was achieved at 30 °C with 1 l/min purging gas stream.

KEYWORDS:

Biomethane, CO_2 adsorption, concentration swing adsorption

1 INTRODUCTION

Biogas is developed by the anaerobic fermentation of organic matter. It consists of 50-75 vol.-% methane (CH_4) and 25-45 vol.-% carbon dioxide (CO_2) [1]. Its energetic use provides the opportunity to substitute fossil fuels and hence reducing the emission of CO_2. Usually biogas is used to produce electricity in combined heat and power plants; however, due to the decentralized location of most biogas plants, an adequate use of the heat is not always possible. By separating CO_2, water and trace components, the gas composition can be adjusted to the natural gas grid's quality standards. After this upgrading the so called biomethane can be injected into the gas grid, transported in it and thus used efficiently in combined heat and power plants close to a heat sink [1].
In many European Union countries, the access to the gas grid is guaranteed. All gas contaminants have to be removed and the CH_4 content has to be above 95 vol.-% [2]. The German Federal Government aims at an injection of biomethane of 10 % of the natural gas consumption until 2030 (6 % in 2020) [3]. 1000 to 1500 biogas upgrading plants are necessary to achieve this until 2020 [4]. In November 2012, 107 plants injected biomethane to the German natural gas grid [5].
Currently, high pressure water scrubbing, pressure swing adsorption and amine scrubbing are the main technologies used for upgrading biogas to biomethane [6]. The investment and operational costs of a biogas treatment system allow an economic use only for larger scale biogas plants or for crude gas streams above 500 m³/h [7]. While for water scrubbing and pressure swing adsorption the electrical energy demand for the gas compression is of significance, the upgrading with amine scrubbing needs large amounts of thermal energy for the regeneration.
The Institute of Combustion and Power Plant Technology (IFK) is investigating the CO_2-separation of biogas for upgrading it to biomethane using ion exchange resins which are functionalized with amines. The adsorption of CO_2 on ion exchange resins [8] and the reaction with amines fixed on polymers [9] is known for a long time. The aim is to investigate an innovative technique for CO_2 separation from biogas, which can reduce the energy demand, the capital expenditure and the operational costs compared to the conventionally used techniques. Therefore it could be applied economically also on smaller biogas plants. This upgrading process should be able to separate the total amount of CO_2 from previously dried and desulfurized biogas. The CO_2 adsorbing abilities of different ion exchange resins are investigated on the laboratory scale with synthetic biogas by varying different parameters, such as adsorption temperature and CO_2 partial pressure. Thereby applicable working points for adsorption and desorption were identified and a continuous plant concept was developed. In [10] the

ability of one ion exchange resins to selectively adsorb CO_2 from biogas was shown. The regeneration occurred by rising the temperature and using air as purging gas. In a continuous lab-scale plant numerous variations of process parameters were carried out, optimization possibilities were demonstrated and product gas purity up to 98 vol.-% methane was achieved.
This contribution presents results of a new ion exchange resin. The lab-scale plant was operated at constant temperatures and the regeneration was done by purging with air, by which a concentration swing adsorption process is achieved. Variations of temperature level and the purging gas stream were carried out and a simple energy balance was done.

2 MATERIALS AND METHODS

2.1 The adsorbent

The used ion exchange resin is an industrial product. It consists of macroporous styrene beads with around 0.6 mm diameter and is used in a packed bed. The resin is functionalized with amine groups which are able to bind CO_2 molecules. The specific area of the beads is about 50 m²/g. After a screening of about 20 resins for their CO_2 adsorption ability this one was selected for detailed examinations, which are presented within this work.

2.2 Set-up and experimental procedure of equilibrium loading experiments

In the laboratory setup shown in Figure 4 equilibrium loading experiments at different temperatures and partial pressures are determined. The setup consists of a glass column filled with about 140 g of the polymer resin. Its inner diameter amounts to 37 mm and the length is 430 mm. Through a double shell it can be cooled or heated with water. Tree thermocouples are distributed over the height inside the resin bed to observe the temperature. The gas flows through the column at atmospheric pressure. For equilibrium loading experiments synthetic biogas consisting of CO_2 and CH_4 is provided by mass flow controllers (MFC). With the same set-up the CO_2 desorption is examined.

For this, compressed air adjusted by a MFC is led through the column and the temperature is kept constant or is increased during the experiment.
With infrared analyzers, the CO_2 and CH_4 concentrations of gas streaming through the column can be measured. When the temperatures inside the column are constant and the outlet gas concentration equals the inlet no more CO_2 is adsorbed on the resin or desorbed from it and the equilibrium loading is reached.
In the set-up shown in Figure 5 equilibrium loading is determined gravimetrically. Resin filled glass u-tubes are maintained at constant temperature in a water bath while a mixture of nitrogen (N_2) and CO_2 streams through them for a certain time at atmospheric pressure.

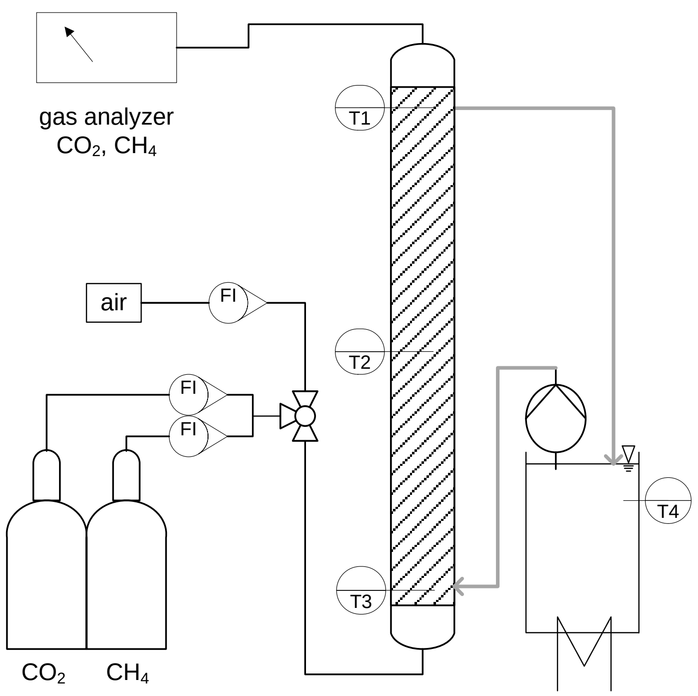


Figure 4: Set-up for equilibrium loading and breakthrough experiments.

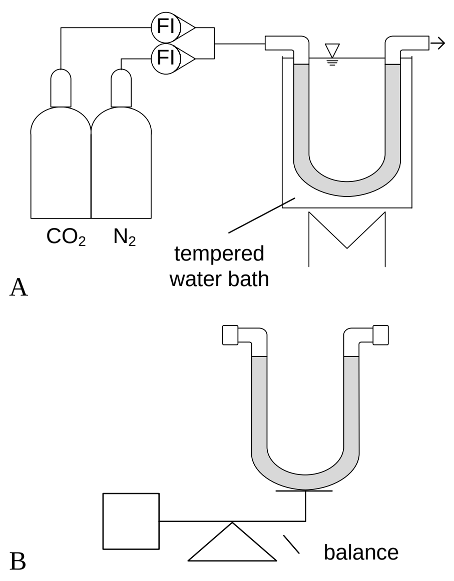


Figure 5: Experimental set-up to determine the equilibrium loading gravimetrically with resin filled u-tubes. A: loading at constant in temperature in water bath. B: balancing the u-tubes with caps.

With the known weight of the u-tube and the resin in it, the equilibrium loading is calculated from the weight change. Therefore the u-tubes are closed with screwed caps and weighed on a precision balance with a resolution of 0.001 mg. Regeneration is done with N_2 at 60 °C to avoid the sorption of water from air, which would disturb the gravimetrical measurement.

1.1 2.3 Set-up of the continuous lab-scale plant and experimental procedure

For the continuous experiments a lab-scale plant was setup (Figure 6) as described in previously [10]. It consists of two resin filled columns which are interconnected with electronically controlled magnetic valves. The columns are of the same type as the one of the equilibrium loading experiments. Tempered water flows through their double shell to keep the process temperature level constant. While one column is loaded from the bottom with synthetic biogas, the other one is regenerated and therefore purged with air from above. Before CO_2 could break through, all magnetic valves are switched at the same time and the second column is loaded while the first one is regenerated. The temperatures inside the resin are monitored, and the concentrations of CO_2 and CH_4 are measured with infrared analyzers during the whole experiment. The length of adsorption and desorption depends on the specific working capacity at the conditions of the experiment. Before each experiment, the temperature of the water bath is adjusted and the water is led through the columns' double shells. When the temperatures inside the resin reached the process temperature the test is started. Raw gas composed of 50 vol.-% CO_2 and 50 vol.-% CH_4, is led through one column while the other one is purged with air. Due to safety reasons, CH_4 is temporally substituted by 50 vol.-% N_2. This is valid as neither a reaction of the resin with CH_4 nor with N_2

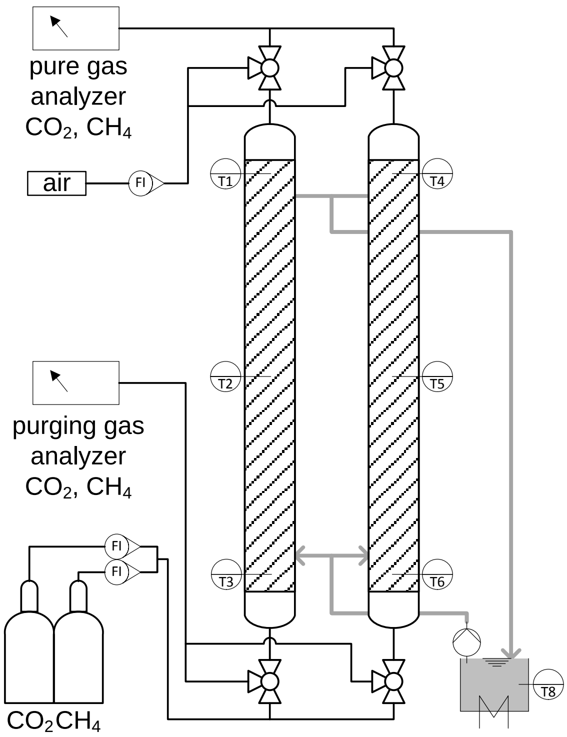


Figure 6: Set-up of continuous lab-scale plant consisting of two columns tempered with water and interconnected with magnetic valves.

was observed. The raw gas stream amounts to 0.5 l/min while the purging gas is varied between 0.5 l/min, 1 l/min, 2 l/min, 4 l/min and 8 l/min.

After a few cycles of adsorption and desorption, steady state is reached and each loading cycle has nearly the same duration compared to the one before. The temperature profiles are stable and the maximum and minimum levels of each cycle stay the same. The conditions were maintained until at least 12 cycles with constant duration are gained. From these, the mean working capacity is calculated from the gas analysis.

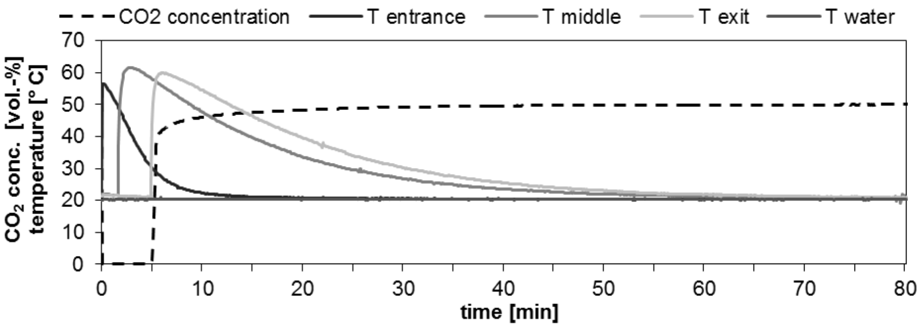


Figure 7: CO_2-concentration an temperatures inside the resin during equilibrium loading experiment with 1 l/min synthetic biogas consisting of 50 vol.-% CO_2 and 50 vol.-% CH_4, column kept at 20 °C.

3 RESULTS AND DISCUSSION

3.1 Equilibrium loading experiments

Figure 7 shows the CO_2 concentration in the gas leaving the column in a breakthrough experiment (dashed line). The solid lines illustrate the temperatures measured inside the resin and the water temperature. In this experiment the column was kept at 20 °C and 1 l/min synthetic biogas consisting of 50 vol.-% CO_2 and 50 vol.-% CH_4 streamed through it.
During the first 5 minutes, the total amount of CO_2 is adsorbed until the breakthrough occurs. The CO_2 -concentration increase is sharp until around 40 vol.-% CO_2 and fattens out until the equilibrium is reached after about 80 minutes. The three thermocouples placed at the entrance, in the middle and at the exit of the column show the shift of the reaction zone through the column and a sharp increase at the moment the CO_2 is adsorbed. When the breakthrough occurs, the temperatures in the resin are still significantly above the water temperature. With decreasing temperatures, the CO_2 -concentration increases until the equilibrium is reached. At the end of the experiment, the CO_2-loading of the resin amounts 1.39 mol CO_2/kg resin.
By varying temperature and partial pressure in the gravimetrical determinations of equilibrium loading, the adsorption isotherms are obtained. Figure 8 shows them for 20 °C and 60 °C in the range of 0.02 vol.-% to 100 vol.-% CO_2 partial pressure for the examined resin. It clearly can be seen that the loading increases with decreasing temperature and increasing CO_2 partial pressure. The gravimetrically measured equilibrium loadings correspond well with the loadings calculated from the breakthrough experiments. 1.47 mol CO_2/kg resin were reached at 50 vol.-% CO_2 and 20 °C. The slightly lower loading of the break through experiment (Figure 7) is reducible to regeneration with air and therefore a small remaining loading at the end of desorption.
The clear influence of partial pressure in Figure 8 is advantageous for concentration swing adsorption, as decreasing CO_2 -concentration induces a decreasing CO_2-loading of the resin.

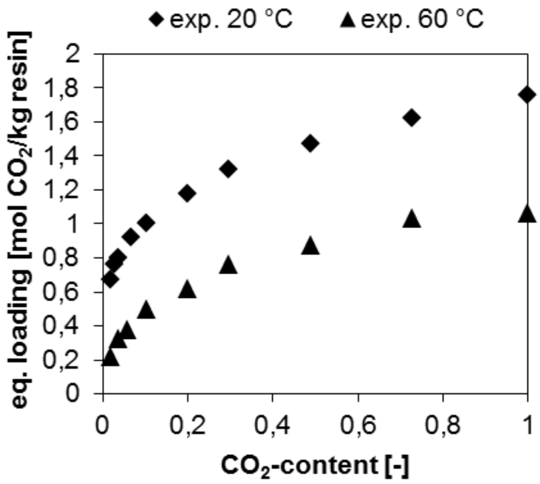


Figure 8: Adsorption isotherms for C(in mixture with ♪ for examined resin at 20 °C (diamonds) and 60 °C (triangles) measured gravimetrically.

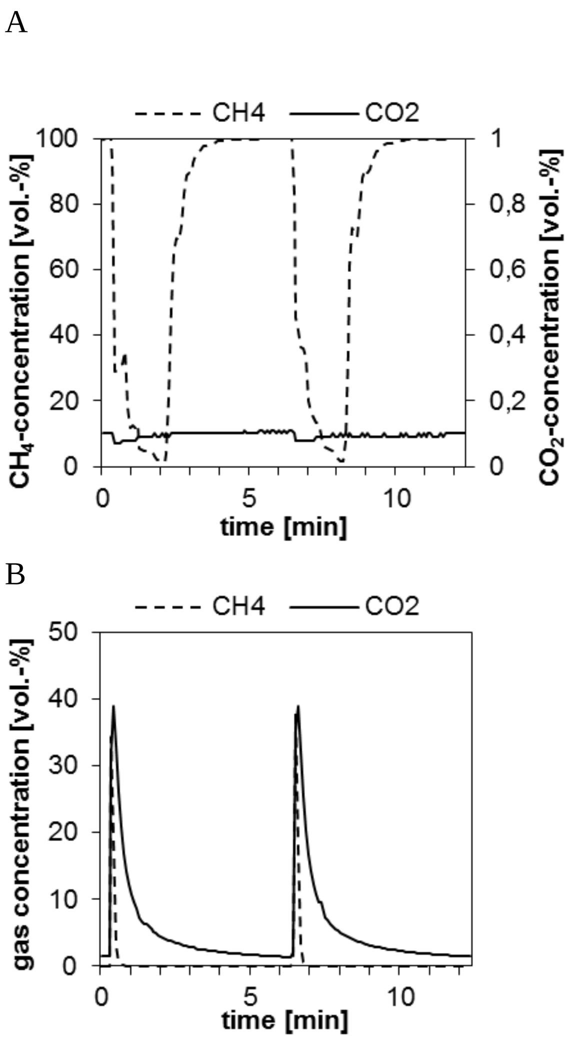


Figure 9: CO_2 and CH_4-concentrations of cleaned gas (A) and purging gas (B) during continuous experiments at 50 °C, 0,5 l/min raw gas and 4 l/min air.

3.2 Concentration swing adsorption at the continuous lab-scale plant

Figure 9 shows the CO_2 and CH_4-concentrations for the cleaned gas (A) and the purging gas (B), respectively, during an experiment at 50 °C, 2 l/min synthetic biogas with 50 % CO_2 and 50 % CH_4. The air flow to purge the resin at regeneration was set to 4 l/min. It can be seen in Figure 9 A that the CH_4-content of the cleaned gas amounts to 100 % between the changes of operating mode. After the switching of the valves the CH_4-concentration drops down and increases again to 100 %. This phenomenon leads to an average CH_4-purity of 70 %. With the optimization of valve switching presented in [10] the purity can be increased up to 98 % CH_4. The concentration of CO_2 amounts to about 0,1 % all the time und thereby in the range of measuring uncertainty.

Figure 9 B shows the concentrations in the purging gas. The CO_2-concentration shows the typical curve shape for desorption. The CH_4-concentration amounts to nearly 0 % all the time. Just after changing the valves, a short methane peak occurs due to the intermixture with the cleaned gas remaining in the now regenerated column. With the optimized switching of valves the methane loss can be reduced significantly [10].

To reach a high CH_4-purity, the time between valves switching has to be as long as possible. Therefore the amount of CO_2 adsorbed from the resin during one loading, which is defined as working capacity, has to be as high as possible. At steady state conditions, the quantities of adsorbed and desorbed CO_2 are equal. Possibilities to increase the working capacity are presented in the following.

3.3 Variation of process parameters in continuous lab-scale plant

Figure 10 shows the obtained working capacities for the parameter variation in the continuous lab-scale plant. The x-axis shows the temperature level which was adjusted by the water streaming in the double shell of the columns. The different signs mark the series with the purging gas streams 0.5 l/min, 1 l/min, 2 l/min, 4 l/min, 8 l/min. It is obvious, that the raising of the purging gas stream induces an increase of the working capacity at all temperature levels. For lower temperatures, slightly higher working capacities are reached. This tendency can be explained from the isotherms shown in Figure 8 which are flatter at higher temperatures within the examined range. The effect of increased purging gas is weaker at 70 °C than it is at 30 °C, especially at 4 l/min and 8 l/min. For the same purging gas stream but different temperature levels, the resulting working capacity is in the same range. Only at 70 °C with 4 l/min and 8 l/min purging gas, the working capacity is lower than could have been expected from the other temperatures. During regeneration, the temperature inside the resin decreases because the CO_2-desorption consumes heat. Additionally the gas streams enter the columns with room temperature and cool the resin. This cooling effect is stronger at high purging gas streams and high temperatures, whereby disadvantageous conditions for the regeneration result and thus the working capacity decreases.

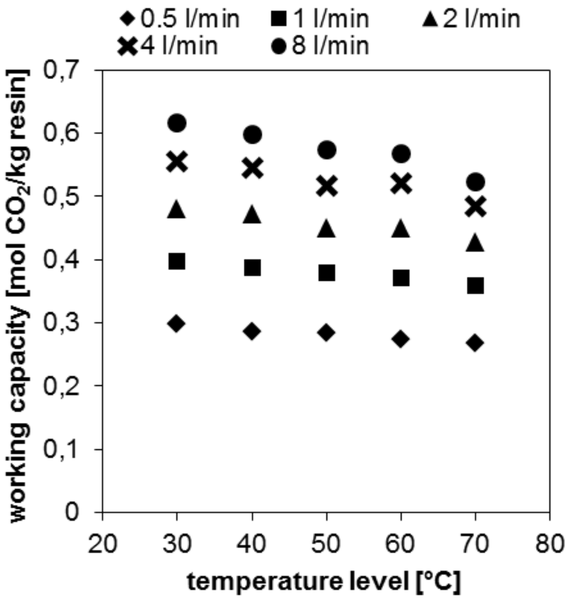


Figure 10: Working capacities of the parameter variation of the continuous experiments.

Comparing the working capacities from the continuous experiments with the equilibrium loading isotherms, it can be seen, that only a part of the potential of the resin is used in the examined concentrations swing adsorption. A further improvement of the working capacity should be possible.

3.3 Energy demand

To estimate the energy demand of the continuous lab-scale pant a simple energy balance is calculated. The electrical and the thermal energy input are considered as well as the gas loss by column switching. The process is a concentration swing adsorption, no thermal energy has to be supplied or dissipated because the heat released at adsorption is consumed during desorption. In the best case, thermal energy only has to be expended to compensate the heat leaving the system with the product gas streams. The room temperature is calculated with 20 °C. For this balance all further the energy losses e.g. through the shells are neglected but no heat recovery systems are considered. The electrical energy demand of the plant depends on the necessary compression to overcome the pressure loss of the packed bed. By measurements, the values for the raw gas and the different purging gas streams were determined. To allow a comparison to the thermal energy demand, an electrical efficiency factor of 35 % was set. With the optimized column switching to minimize the intermixture of product, gas streams up to nearly 100 % CH_4 are reachable [10]. While maximizing the methane purity, however, methane loss occurs. To allow the comparison of the presented resin to others, the void volume of the resin bulk is used. For the energy balance calculated, it is defined that for every column switching, 10 % of the void volume of methane are lost.

Figure 11 shows the results of the energy balance. They are presented as the loss of energy content of the raw gas in % for the different process temperatures and the variation of purging gas. It is obvious that the energy loss due to thermal and electrical energy input increase with increasing purging gas streams at all temperature levels. While the electrical energy demand is independent from temperature the expended thermal energy increases with increasing temperature level and leads to significant differences. The gas loss caused by the switching of the columns shows only slight differences between the temperature levels; however, higher purging gas streams induce a lower methane loss. This is due to significant increase of the working capacity with an increasing volume stream of purging gas. Overall, it can be seen, that the purging gas stream of 1 l/min achieves the lowest energy loss for all temperature levels.

On the basis of this energy balance, important optimization possibilities could be derived. An increase of the working capacity of the ion exchange resin with a decrease of the void volume could significantly reduce the gas loss caused by column switching. However, a lower void volume of the bulk could increase the pressure loss of the resin bulk.

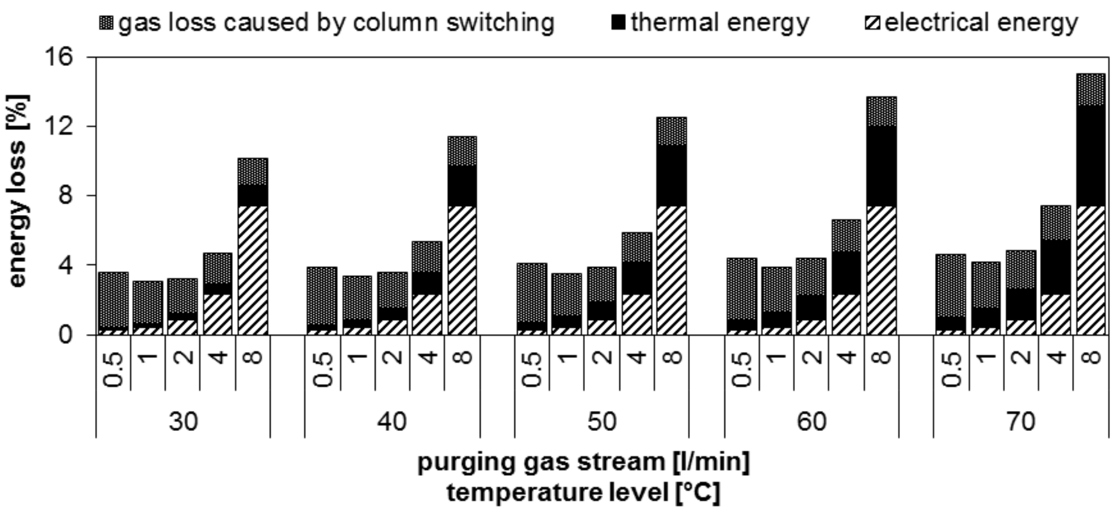


Figure 11: Loss of energy content of the raw gas in % for the different process temperatures and the variation of purging gas for the experiments with the lab-scale plant.

4 SUMMERY AND OUTLOOK

In adsorption experiments the ability of the examined ion exchange resin to adsorb CO_2 from gas streams was shown. Desorption of CO_2 was successfully carried out by purging the resin with air. By conducting equilibrium loading experiments at different partial pressures and temperatures, two adsorption isotherms for the examined resin were established. From the continuous experiments working capacities for temperature levels of 30 °C, 40 °C, 50 °C, 60 °C and 70 °C as well as purging gas streams of 0.5 l/min, 1 l/min, 2 l/min, 4 l/min and 8 l/min were determined. With lower temperatures, higher working capacities were achieved for the examined resin especially with high purging gas streams. The energy balance showed the influence of thermal and electrical energy demand and of the gas loss caused by column switching. The lowest energy loss was achieved at 30 °C with 1 l/min purging gas stream. It can be summed up that the examined ion exchange resin is suitable for the application in the presented concentration swing adsorption process and the energy demand could be reduced by the choice of advantageous parameters. Ion exchange resins with higher working capacities would be beneficial as the gas loss caused by the column switching would be reduced. Examinations of more resins will follow accompanied by an optimization of the resins. The demonstration of the proof of concept will follow in an up-scaled plant working with real biogas.

ACKNOWLEDGMENT

Part of this work was carried out in the scope of the project „2-stufiges Konzept zur fermentativen Produktion von Wasserstoff und Bioerdgas durch innovative Gasaufbereitung“ (Förderkennzeichen: 03SF0351). The authors gratefully thank the BMBF and the companies EnBW AG, Purolite Deutschland GmbH and RBS wave GmbH for the financial and scientific support.

REFERENCES

[1] FNR, *Biogas – an introduction*, Gülzow Germany 2009, http://www.fnr-server.de/ftp/pdf/literatur/pdf_329-biogas--an-introduction_engl.pdf (12.07.2013).

[2] P. Weiland, *Applied Microbiology and Biotechnology* 2010, *85 (4)*, 849.

[3] Bundesregierung, *Eckpunkte für ein integriertes Energie und Klimaprogramm (Beschluss der Kabinettsklausur von Meseberg vom 23./24.08.2007)* 2007, www.bmwi.de/BMWi/Redaktion/PDF/E/eckpunkt-fuer-ein-integriertes-energie-undklimaprogramm,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf.

[4] DENA, *Biomethan im KWK- und Wärmemarkt. Status Quo, Potentiale und Handlungsempfehlungen für eine beschleunigte Marktdurchdringung. Zusammenfassung und Handlungsempfehlungen* 2010, http://www.dena.de/fileadmin/user_upload/Presse/studien_umfragen/Biomethan/Studie_Biomethan_im_KWKundwaermemarkt.pdf (12.07.2013).

[5] DENA, *Branchenbarometer Biomethan 2/2012: Daten, Fakten und Trends zur Biogaseinspeisung*, Berlin, http://www.biogaspartner.de/fileadmin/biogas/documents/Branchenbarometer/Branchenbarometer_Biomethan_2_2012_Download.pdf 2012.

[6] A. Petersson, A. Wellinger, in *IEA Bioenergy, task* 2009.

[7] BASE TECHNOLOGIES GmbH München, *Biogasaufbereitungssysteme zur Einspeisung in das Erdgasnetz – ein Praxisvergleich*, Solarenergieförderverein Bayern e. V. München 2008.

[8] D. K. Fuller, Removal of carbon dioxide and water using a solid amine adsorption bed for extended space flight, *Master of Science thesis*, Rice University 1993.

[9] A. Diaf, R. M. Enick, E. J. Beckman, *Journal of Applied Polymer Science* 1993, *50 (5)*, 835.

[10] K. Raab, M. Lamprecht, K. Brechtel, G. Scheffknecht, *Eng. Life Sci.* 2012, *12 (3)*, 327.

A NOVEL APPROACH FOR BIOGAS UPGRADING BASED ON A CHEMICAL SCRUBBING PROCESS WITH SOLVENT REGENERATION AT LOWER HEAT VALUES

B. Klein, D. M. Castrillón Torres, B. Heidel, G. Scheffknecht
University of Stuttgart, Institute of Combustion and Power Plant Technology (IFK)
IFK, Pfaffenwaldring 23, 70569 Stuttgart, Germany
Barbara.Klein@ifk.uni-stuttgart.de

ABSTRACT: Amino acid salt (AAS) solutions were investigated to estimate their suitability for application in a novel biogas upgrading process, based on chemical scrubbing. The suggested process is characterized by a desorber unit, where the carbon dioxide (CO_2) loaded scrubbing solution is regenerated by a combination of heat and air stripping. The reduction of the CO_2 partial pressure in the gas phase, due to air stripping, results in an enhanced regeneration of the scrubbing solution at lower temperatures, thus also leading to lower process temperatures. The absorption and desorption capacity as well as the stability against thermal and oxidative degradation of the potassium salts of the amino acids ß-alanine, arginine, glycine, histidine and lysine were investigated. Due to high applicable concentrations lysine and glycine achieved the highest working capacities. However, lysine proved in contrast to glycine not to be stable under the proposed operating conditions. With potassium salt solution of glycine a continuously working lab scale plant was operated, proving the process suitable for the continuous absorption of CO_2 from gas streams. By choice of proper liquid to gas ratio it was possible to meet the requirements for the methane concentrations in pure gas at desorption temperatures of 80°C and 60°C.

KEYWORDS: biogas upgrading, chemical scrubbing; amino acid salt solutions

1 INTRODUCTION

Energy from biogas will play an important future role for a secure energy supply and the minimization of greenhouse gas emissions [13]. The main components of biogas are on the one hand methane (CH_4) with 50 to 75 vol.-% and on the other hand carbon dioxide (CO_2) with 25 to 45 vol.-%. Additionally, minor amounts of water (H_2O), hydrogen sulfide (H_2S), nitrogen (N_2), oxygen (O_2) and hydrogen (H_2) can be found [6].

The usage possibilities of biogas are versatile. Thus, it either can be transformed to power and heat in cogeneration units directly at its point of origin or it can be upgraded to natural gas quality and afterwards be injected into the national gas grid. As the demand for heat in the rather rural areas of biogas production is very low, only 35 to 40 % of the original primary energy content of biogas can be used by direct transformation in cogeneration units. A more efficient way of use is the upgrading of biogas and the subsequent injection into the national gas grid. Thereby, the upgraded biogas can be transported via the gas grid and used independently at locations, which offer heat sinks [9].

As natural gas contains about 97 % of flammable gas, the criteria for the methane content of upgraded biogas are of similar magnitude although they might slightly differ depending on country [12]. Thus, besides the removal of minor impurities, carbon dioxide has to be removed. For the removal of CO_2 various processes can be applied. Most commonly employed are pressure swing adsorption, pressurized water scrubbing, membrane separation or absorption processes. Depending on the choice of the methane enrichment procedure several previous purification steps as e.g. the removal of H_2S or water might be necessary [7].

Absorption processes are applied for gas separation purposes and can be classified into physisorption and chemisorption processes. At physisorption, the transition of one component from the gas phase into the liquid phase relies exclusively on physical van der Waals forces between the component and the scrubbing solutions, while at chemisorption the physisorption is overlaid with a chemical reaction of the component with the solvent [11]. Chemisorption is more selective than physisorption and results in a higher loading of the scrubbing solution with the component to be separated, as chemical bonding forces are more powerful than van der Waals forces [7]. A chemical scrubbing process consists of an absorption unit on the one hand and a desorption unit on the other. In the absorber, the raw gas is contacted countercurrently with the scrubbing solution and the treated gas leaves the column at its top while the loaded scrubbing solution accumulates at the bottom of the absorber column and is thence pumped to the desorber, where the regeneration of the scrubbing solution takes place [2]. While low temperatures and a high partial pressure of the component to be separated are beneficial for the absorption, the desorption should be carried out at high temperature and low partial pressure [11].

To date, chemical scrubbing with amines - mostly with monoethanolamine (MEA) - is the chemical scrubbing method of choice for the purpose of biogas upgrading. Amine scrubbing for CO_2 capture is a technically mature process, which was first patented in 1930 and is also applied for CO_2 removal from natural gas. The process is based on the chemical reaction of MEA with carbon dioxide. While the CO_2 absorption usually takes place at near ambient temperature, the loaded amine solution is regenerated by stripping with water vapor at 100 to 120 °C [10]. Another possibility for the regeneration of loaded scrubbing solution would be the flushing with air. By this means, the carbon dioxide partial pressure would be kept at low levels due to the steady fed air, resulting in CO_2 desorption at significant lower temperatures, which would facilitate the integration of the process at existing biogas plants. As MEA degrades in the presence of oxygen [5], the regeneration via air stripping is not suitable for MEA based scrubbing solutions. Recently, notice was attracted to amino acid salts as possible sorbents for CO_2 separation. As amino acid salts are practically nonvolatile due to their ionic structure [1] and supposedly stable against oxygen [4] they might be applicable in a chemical scrubbing process with solvent regeneration based on flushing with air. Amino acids are organic compounds that feature at least one amino group and one acid group. Dependent on the prevailing pH they can exist in three states, the first being the acidic state, the second the zwitterion state and the third the deprotonated zwitterion state. In water the amino acids exist in the zwitterion state. As the first two of the mentioned states are not reactive towards CO_2, the amino acids are deprotonated by adding an equimolar amount of strong base, for example potassium hydroxide to the solution [1]. After deprotonating the acid group the amino acid salt solutions can react with CO_2 like alkanolamines as for example MEA. Amino groups are subdivided into three different types depending on the number of hydrogen atoms attached to the nitrogen atom, namely primary (2 hydrogen atoms), secondary (1 hydrogen atom) and tertiary (no hydrogen). In aqueous solution primary and secondary amino acid salts react with carbon dioxide to form carbamate ions as described in the following equation:

$$CO_2 + 2\ R_1R_2NH \leftrightarrow R_1R_2N\text{-}COO^- + R_1R_2NH_2^+ \quad \text{(Eq. 1)}$$

Besides the formation of carbamate ions the amino acid salts also bind CO_2 as bicarbonate as they lead to the formation of hydroxide ions, which can react with CO_2 to bicarbonate or depending on pH to carbonate:

$$H_2O + R_1R_2R_3N \leftrightarrow OH^- + R_1R_2R_3NH^+ \quad \text{(Eq. 2)}$$

$$CO_2 + OH^- \leftrightarrow HCO_3^- \quad \text{(Eq. 3)}$$

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+ \quad \text{(Eq. 4)}$$

$$HCO_3^- \leftrightarrow CO_3^{2-} + H^+ \quad \text{(Eq. 5)}$$

While amino acid salts with primary and secondary amino groups can form carbamate ions according to Eq.1, amino acid salts with tertiary amino groups only can bind the CO_2 in form of bicarbonate or carbonate (Eq.2 to Eq.5) as they lack the hydrogen atom that needs to be separated in carbamate formation [3, 4]. The theoretically achievable molar carbon dioxide loading amounts according to the above mentioned reaction equations 1 mol CO_2 per mol tertiary amine and 0.5 mol CO_2 per mol primary or secondary amine, respectively. Actually, primary and secondary amino acid salts can absorb more CO_2 as tertiary ones as they can bind the CO_2 not only by formation of carbamate ions but also bind the CO_2 in the form of bicarbonate and carbonate. Regarding the regeneration of the scrubbing solution, it requires more energy to desorb the CO_2 that is bound as carbamate than the CO_2 that forms carbonate in the solution as the reaction enthalpy of the latter is lower[8]. Thus, it is desirable to bind as much CO_2 as possible in the form of bicarbonate or carbonate.

In this work, initial investigations were carried out to estimate the suitability of different amino acid salt solutions for their application in the suggested process, where the solvent is regenerated by combining heat addition and air stripping. Therefore, laboratory experiments on the ability of various amino acid salts to absorb CO_2 were performed. Furthermore, the desorption of carbon dioxide of loaded scrubbing solutions was investigated at different temperatures and air fluxes. Additionally, stability tests at high temperature and air stripping were executed to identify suitable amino acids for the proposed process. A continuously working lab scale plant was built and operated with promising amino acids to prove the feasibility of the proposed process.

2 MATERIALS AND METHODS

2.1 Materials

All chemicals were purchased at Carl Roth GmbH + Co. KG, Germany with purities of at least 99.0% and used without further purification. The investigated amino acids are displayed.

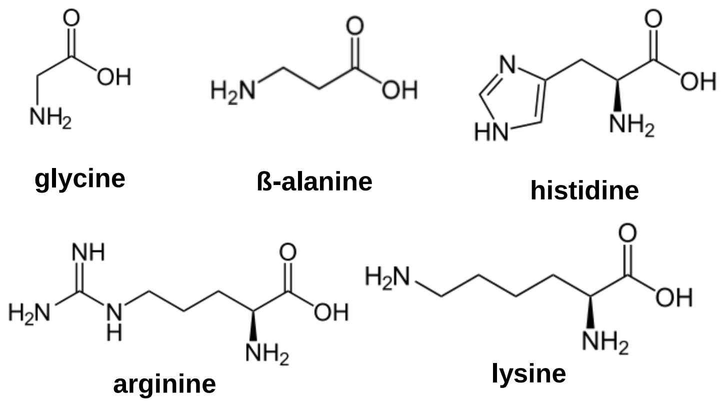


Fig. 1: Chemical structure of the five investigated amino acids

Equimolar solutions of amino acid and potassium hydroxide were prepared using deionized water by weighing with precision of ±1 x 10^{-2}. In the following, the AAS are abbreviated with K-ß-Ala, K-Arg, K-Gly, K-His and K.-Lys for the potassium salts of ß-alanine, arginine, glycine, histidine and lysine respectilvely. The gases, CO_2 (99.95%) and CH_4 (99.99%) were obtained from Westfalen AG, Germany.

2.2 Experimental setup and procedure

The setup for the absorption as well as for the desorption experiments is displayed in Fig. 2.

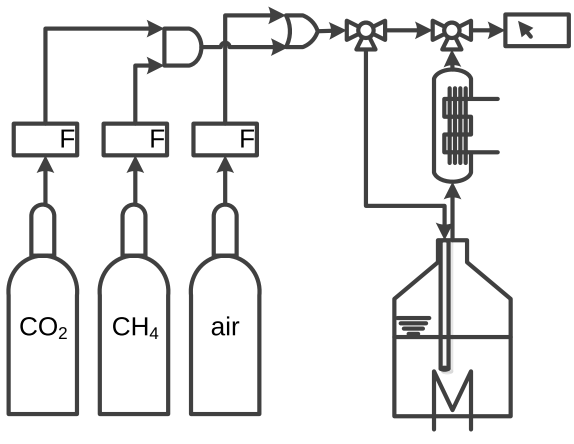


Fig. 2. Experimental set-up for absorption and desorption experiments

By means of Mass Flow Controller (=MFC) synthetic biogas fluxes of different compositions can be adjusted. Firstly, the gas flux is lead via the bypass through the gas analyzer in order to record the starting composition of the synthetic gas mixture. When the amino acid salt solution, which is tempered by a heating plate, reaches the required temperature, the bypass is closed and the gas is lead through a frit into the glass flask, filled with the amino acid salt solution. The gas, which leaves the solution is lead through a chiller in order to condense the water that was swept along and the gas concentrations of methane and carbon dioxide are measured. The experiment is brought to a stop when no further carbon dioxide is absorbed, which is the case when the gas concentration, measured at the outlet equals the concentration measured before the experiment. In addition to the gas concentration the pH and the temperature of the solution are measured and all data are recorded at intervals of five seconds. The amount of absorbed carbon dioxide can be calculated by integrating the CO_2 concentrations at the outlet. Additionally, the carbon dioxide loading of the solutions is determined afterwards gravimetrically with hydrochloric acid. By this means the CO_2 equilibrium loading of different amino acids was determined for different temperatures and different concentrations as function of the CO_2 partial pressure in the gas phase.

For the desorption experiments, the same experimental set-up is applied. In that case, instead of synthetic biogas, air is used. A particular amount of air is led by the MFC via the frit through the loaded scrubbing solution for 30 minutes, while it is heated to the desired temperature. The desorbed amount of carbon dioxide is determined by integrating the measured carbon dioxide concentration at the outlet as well as gravimetrically. The performance of regeneration was determined at different temperatures and for different air fluxes.

Besides, stability tests were carried out to investigate to which extend the amino acids are stable against oxidative and thermal degradation at the proposed operating conditions. Therefore, the carbon dioxide loaded amino acid salt solutions are tempered over a heating plate to the desired temperature and air is lead constantly through the solutions for thousand hours (see

Fig. *3*). Roughly each 250 hours samples are taken and the amino acid content of the solutions is determined titrimetrically. Titrations are carried out with 1 M hydrochloric acid standard solution, using the TitroLine® alpha plus from SI Analytics with the combination electrode Science Line N 62. Titration curves are evaluated with the software TitriSoft 2.6.

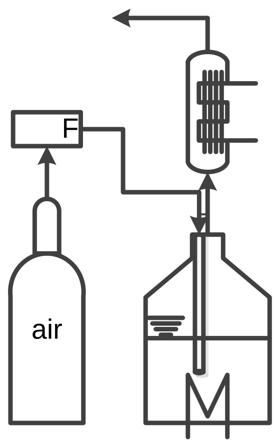


Fig. 3.: Experimental set-up for degradation experiments

Moreover, a continuously working lab scale plant was built and operated with the most promising amino acid salt solution to investigate whether a carbon dioxide rich biogas stream can continuously be upgraded by the proposed process. The plant consists of an absorber unit at the one hand and a desorber unit on the other. Synthetic biogas can be introduced at the bottom of the absorber column. The amount and the composition of the synthetic biogas stream is freely adjustable over the MFCs and the gas concentrations of the raw gas stream can be measured by leading it via bypass directly over the analyzer. Amino acid salt solution is lead counter currently from top to the bottom through the absorber column and thereby absorbs the carbon dioxide in the raw gas. The pure gas leaves the absorber and its composition is analyzed while the loaded scrubbing solution accumulates at the bottom of the absorber and is lead over a heat exchanger to the desorber column where it is heated to the desired regeneration temperature and brought in contact with a freely adjustable flux of stripping air. The stripping gas leaves the desorber at the top of the column and is analyzed while the regenerated amino acid salt solution is pumped via a heat exchanger to the absorber top again.

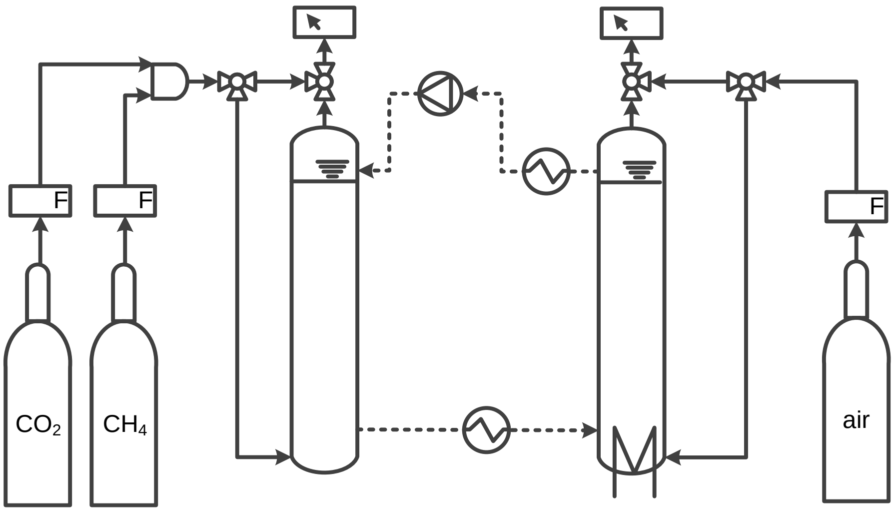


Fig. 4: Continuously working lab scale plant with absorption unit (left side) and solvent regeneration (right side) by combining heat supply with air stripping

3 RESULTS AND DISCUSSION

In Fig. 5 the equilibrium loading of different amino acid salt solution is shown as a function of amino acid salt concentration in the scrubbing solution. The concentrations are referred to as mol amino group (AG), not as mol amino acid per liter solution to enable a comparison between the amino acids at the same amount of functional groups present. The absorption experiments for these investigations were carried out at temperatures of 30°C and at a CO_2 partial pressure in the gas phase of 50 vol.-%, being the reference absorption conditions in these investigations. In the figure it is shown that the amino acids, which only hold primary amino groups, namely K-β-Ala, K-Gly and K-Lys, can absorb significantly more CO_2 than those, which also feature secondary or tertiary amino groups (e.g. K-His or K-Arg) at the same amount of functional groups present in the solution. Moreover, the increase of the CO_2-loading with higher concentrations of the solutions is less pronounced at the latter. Nevertheless, it is clearly visible though not very surprising, that higher concentrations lead to higher CO_2-equilibrium loadings. As high concentrated amino acid salt solutions tend to form precipitates at the contact with carbon dioxide it was necessary to define the highest applicable concentration for each amino acid salt. The formation of precipitations at absorption experiments at 30°C and 50 vol.-% CO_2 partial pressure was defined as criterion for exclusion. These conditions can be seen as the worst case scenario in real biogas plant as they positively affect the formation of precipitations. The highest applicable concentration of each amino acid can be derived from Fig. 5. K-Arg and K-Lys as well as K-Gly solutions can be applied at high concentrations of 4 and 3.5 mol AG/L, respectively. The AAS solutions of lysine and glycine can also absorb very high amounts of CO_2 at these concentrations.

To evaluate the different AAS for their applicability in a continuously working process it does not suffice to take a look at the absorption capacities but the ability to desorb the carbon dioxide from the AAS solutions in the regeneration unit is of equal importance.

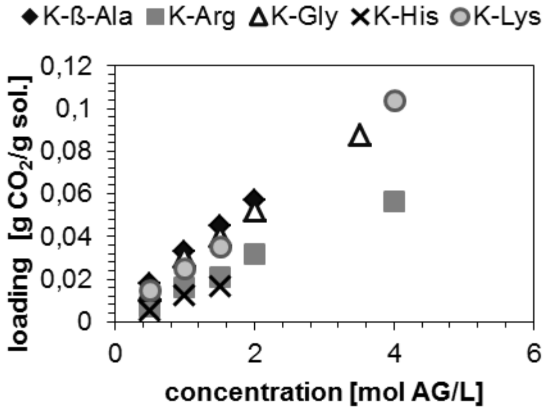


Fig. 5: Equilibrium loading of different AAS solutions at 30°C and CO_2 partial pressure of 50 vol.-% against AAS concentration in the solution

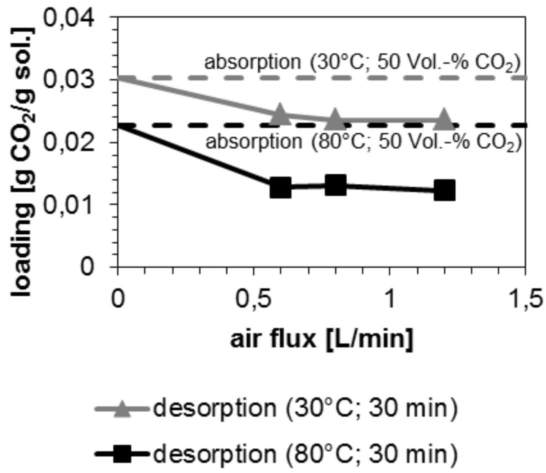


Fig. 6: Remaining carbon dioxide loading of 1M K-Gly solution after 30 min desorption experiments at 80°C and 30°C at different fluxes of stripping air (dotted lines = equilibrium CO_2 loading at 30°C (grey) and 80°C (black) and CO_2 partial pressure of 50 vol.-%)

In

Fig. 6, results from desorption experiments of 1 M K-Gly solutions are depicted. The dotted grey and black lines represent the CO_2 equilibrium loading of 1 M K-Gly solution at 30°C and 80°C, respectively. The 30°C equilibrium loading also equals the loading of the solution at the beginning of each desorption experiment. Thus, the difference in the carbon dioxide loading between the dotted black and the dotted grey line equals the amount of CO_2 that can be desorbed from the solution only by the effect of temperature increase. Focusing on the continuous lines, one can see the effect of air stripping. The stripping with pressurizes air, which results in a low carbon dioxide partial pressure significantly enhances the CO_2 desorption. Nevertheless, the increase in the air flux does not result in appreciable improved solvent regeneration, at least not under the here shown experimental conditions with stripping time of 30 minutes.

Similar to the reference condition for the absorption (30°C; 50 Vol.-% CO_2), the desorption for 30 minutes at 80°C and with a flux of stripping air of 0.8 L/min was defined as reference for the desorption. Furthermore, the term of the working capacity was introduced, to be able to compare the performance of the different investigated amino acids. The working capacity (WC) is defined as the difference between the carbon dioxide equilibrium loading of a solution after absorption at 30°C and 50 vol.-% carbon dioxide and the loading after desorption for 30 minutes at 80°C and the stripping with an air flux of 0.8 L/min. In Fig. 7 the desorption performance of the investigated amino acid salt solutions at concentration of 1 M AG/L are displayed. In the first graph the CO_2 that could be removed from each AAS solution within the regeneration experiment at reference condition is expressed as percentage of the CO_2 that could be absorbed at reference conditions. It can be seen that in the case of K-His solution more than 90% of the initially, absorbed CO_2 , can be desorbed in the regeneration experiment again. This is considerably more in comparison to all the other investigated amino acids, where only 40 to 60% of the initially absorbed CO_2 can be desorbed. This observation can be explained by the chemical structure of histidine. Histidine is the only one of the investigated amino acids, which also features a tertiary amino group. As tertiary amino groups cannot react with the CO_2 , to carbamate a significant amount of the absorbed CO_2 in the solution is present as carbonate, which is easily desorbed. The second graph (B) of Fig. 7 however shows the absolute working capacity of the investigated amino acids at a concentration of 1 M AG/L. Although histidine performs particularly well in terms of relative desorbed CO_2, the working capacity is not very good as K-His solutions cannot absorb a significant amount of CO_2 to begin with. In terms of working capacity K-β-Ala and K-Gly solutions perform best, both of them being amino acids, which only feature one primary amino group.

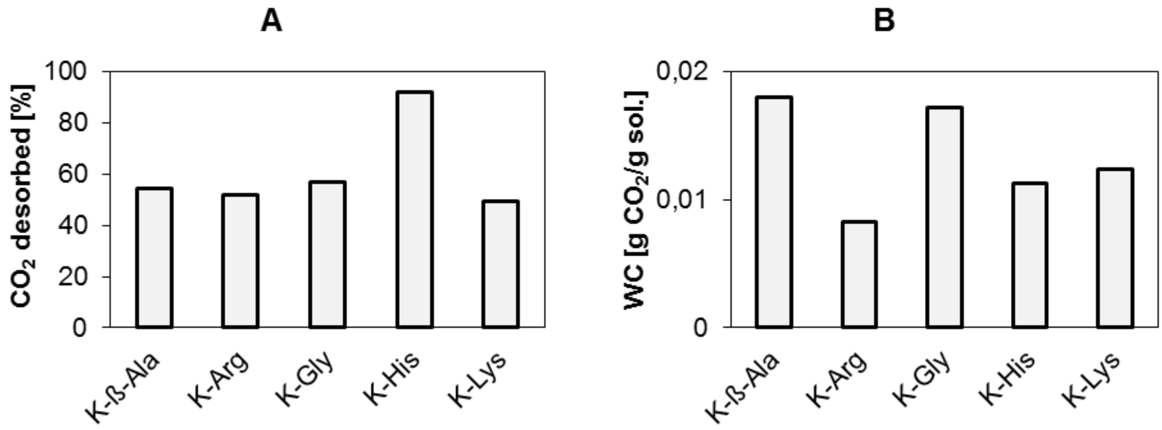


Fig. 7: Comparison of the desorption performance of the investigated AAS solutions at concentration of 1 mol AG/L. A: desorbed CC in %, referring to equilibrium loading at reference conditions for absorption; B: working capacities of the solutions in [g CC/g sol.]

The influence of amino acid salt concentration on the working capacities is shown in Fig. 8. It can be seen that the working capacity increases with increasing amino acid concentrations in the solution, although not linear. The highest working capacities within the investigated amino acid salt solutions were achieved by 3.5 M K-Gly and 4.0 M K-Lys solutions (concentration declaration referring to M AG/L).

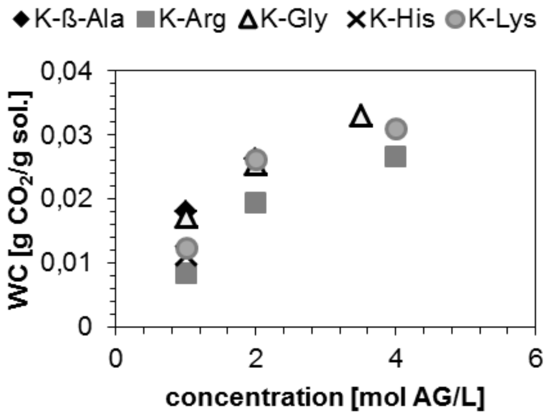


Fig. 8: Working capacity (WC) of the AAS solutions as function of AAS concentration

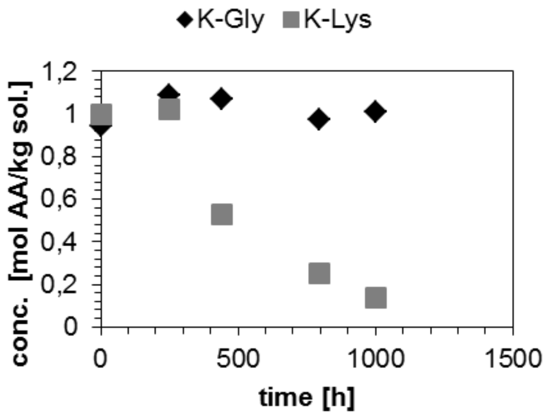


Fig. 9:Concentration of K-Gly and K-Lys solutions at degradation experiment at 80°C and air stripping over time

As high working capacities result in low liquid to gas ratios and small plant dimensions, L-Gly and K-Lys solutions seemed promising candidates for the investigated process.

Thus, stability tests were carried out and the results are shown in Fig. 9. It is clearly visible, that the potassium glycinate solution is much more stable than the potassium lysinate solution at the experiment conditions. While the concentration of K-Gly solution is almost constant over the whole period of the experiment, the concentration in the K-Lys solution decreases significantly already between 250 and 500 h of the experiment. After 1000 hours of air stripping at 80°C only about 20% of the initial concentration remains in the solution. Additionally, visual changes of the K-Lys solution could be observed. Thus, the solution changed after 255 hours from a light yellow to a reddish brown color and foam formation could be monitored.

Facing the results of the degradation experiments 3.5 M K-Gly solutions was identified as the most promising of the investigated amino acid salt solution as it features on the one hand the highest working capacity and on the other hand appears to be stable against oxidative and thermal degradation under the operating conditions. Therefore, further experiments were carried out with 3.5 K-Gly solution. First of all, the equilibrium carbon dioxide loading of the solution was investigated over a wide range of CO_2 partial pressure in the gas phase. Moreover, multiple determinations of the desorbed carbon dioxide at reference regeneration conditions were carried out.

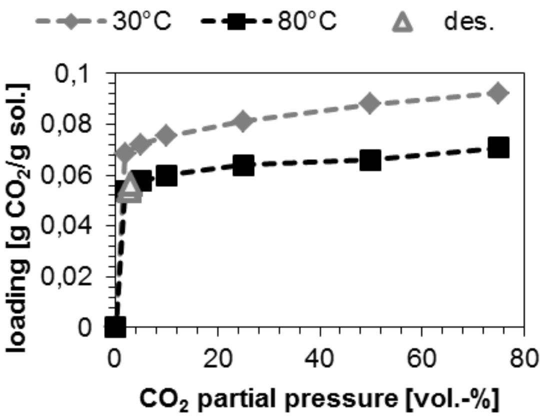


Fig. 10: 30°C and 80°C CC absorption isotherms of 3.5 M K-Gly solution against the CC partial pressure in the gas phase. Triangle framed in grey: loading of the solution after the reference desorption experiment against the CC partial pressure measured in the gas phase at the end of experiment

The results are shown in Fig. 10. The dotted grey line represents the CO_2 absorption isotherm of 3.5 M K.Gly solution at 30°C the dotted black line at 80°C. Moreover, white triangles, framed in grey are visible in the graph. These triangles correspond to the CO_2 loading of the solution after the reference desorption experiment (30 min, 80°C, 0.8 L/min air) over the CO_2 partial pressure in the strip gas stream measured at the end of the desorption experiment As expected, the 80°C isotherm is located beneath the 30°C isotherm as the amino acid salt solution can absorb less CO_2 at elevated temperatures. The effect of the partial pressure also is displayed in the figure. With decreasing CO_2 partial pressures in the gas phase the reachable carbon dioxide equilibrium loading of the solution also decreases. However, the isotherms of 3.5 M K-Gly solution show a relative shallow gradient of CO_2 loading with the partial pressure compared to the differences in the loading that can be achieved by temperature increase. The CO_2 loading after the desorption experiments lay with high precision on the 80°C isotherm at the corresponding partial pressure. Thus, the performance in the desorption experiments can also be described by the absorption isotherms. Hence, by the progression of the absorption isotherms it is possible to estimate the suitability of amino acid salt solutions for the proposed process. On the one hand a large distance between the isotherms of the temperature of absorption and the temperature of desorption is required: On the other hand the isotherms should slope steeply with decreasing partial pressures as this means that the air stripping has a significant influence on the CO_2 desorption, which leads to better performance at low temperatures.

After carrying out the batch experiments a continuous working lab scale plant was operated with 3.5 M K-Gly solution in order to investigate whether it is possible to separate CO_2 continuously from a gas stream at relatively low temperatures with the proposed process. The results from one experiment with desorption at 60°C and a stripping air stream of 1 L/min is shown in Fig. 11. In the first of the three charts, the concentration of methane and carbon dioxide in the pure gas stream are plotted, as well as the carbon dioxide concentration in the stripping air after the desorption unit. The chart in the middle displays the temperatures in the absorber and in the desorber, which were constant over the whole period of the experiment. The last chart shows the calculated CO_2 mass flows that were absorbed or desorbed, respectively. The row gas stream that entered the absorber amounted 1 L/min at the start and was reduced to 0.2 L/min during the experiment, which is marked by the vertical dotted black line. The composition of the row gas stream however was kept constantly at 50 vol.-% for each CO_2 and CH_4. At the start of the experiment the actual gas composition was measured by leading the raw gas via bypass over the analyzer. Therefore, there is a small period of time were the CO_2 and CH_4 concentrations in the first chart add both up to 50 vol.-%. Afterwards the raw gas was lead through the absorber unit and counter currently contacted with the scrubbing solution. At the beginning of the experiment, the complete carbon dioxide flux was separated from the gas stream and sole CH_4 left the absorber as pure gas. Meanwhile, one can see that no CO_2 was desorbed yet as steady state was not reached. Once the freshly prepared solution reached the CO_2 loading that can be achieved in the desorber unit, CO_2 was detected in the stripping gas. From that point on only as much CO_2 can be absorbed as can be desorbed. Thus, the CO_2 concentration in the pure gas increases and the CH_4 concentration decreases until they reach equilibrium and stay constant. At this point the plant is continuously absorbing as much CO_2 as possible under the prevailing conditions. The last chart of Fig. 11 shows that equilibrium in fact was reached as the desorbed CO_2 mass flux equals the absorbed CO_2 mass flux. After reducing the raw gas stream, the whole CO_2 flux could be absorbed resulting in methane concentration of about 100 vol.-%. Additionally, experiments were carried out with solvent regeneration at 80°C, which resulted in better performance in respect to the amount of CO_2 that could be absorbed. The methane concentrations in the stripping gas stream, which represent the methane losses, were at any time in the range of measurement uncertainty of the gas analyzer. The calculated methane losses from those measurements were always below 1 %. As the solvents do not chemically react with methane, the CH_4 losses are solely dependent on the physical solubility of methane in the solvent, which is very low in a plant operated under atmospheric pressure. Thus, it was possible to continuously upgrade a biogas stream with solvent regeneration at very low heat values. The requirements for methane concentrations in the pure gas could easily be met by choice of adequate liquid to gas ratio.

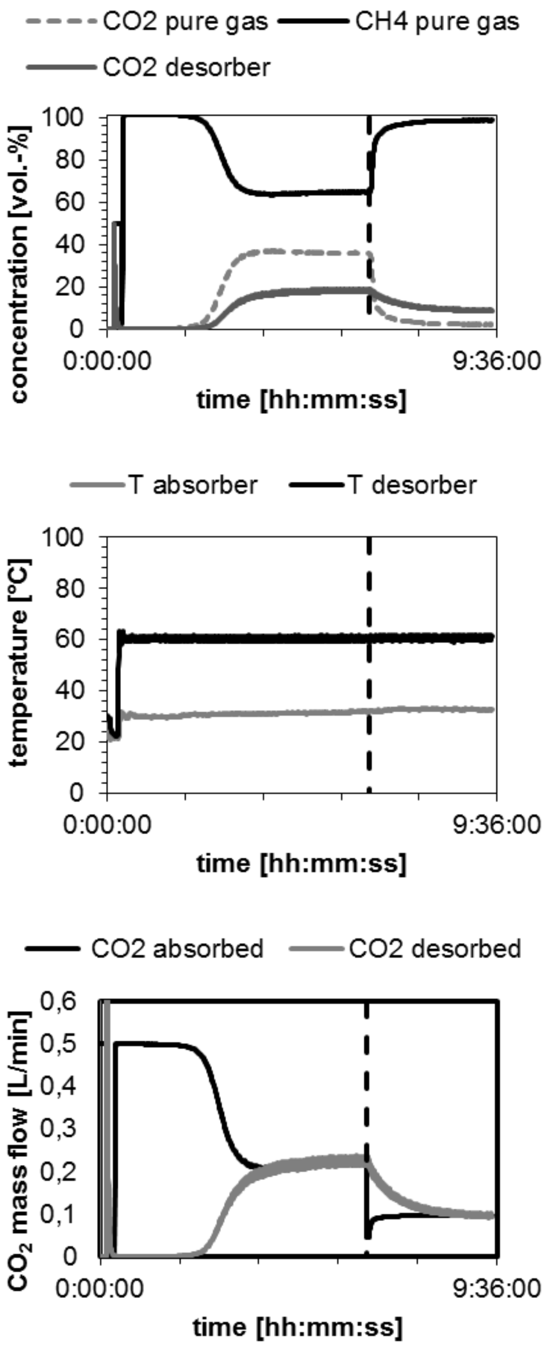


Fig. 11: Operation of continuously working lab scale plant for biogas upgrading with 3.5 M K-Gly solution. Top: gas concentration of CH_4 and CO_2 in the purified gas stream and CO_2 concentration in the stripping gas; Middle: temperature in absorber and desorber; Bottom: mass flow of absolute absorbed or desorbed CO_2; dotted vertical black line: change of raw gas stream from 0.5 L/min to 0.1 L/min for each gas; stripping air: 1 L/min during whole eperiment

4 SUMMARY AND OUTLOOK

In the presented work several amino acid salt solutions were screened for their suitability to be applied in a biogas upgrading process that is based on chemical absorption of CO_2 and the subsequent regeneration of the scrubbing solution by combining heat injection and air stripping. While 30°C is an appropriate temperature for the absorption, desorption is preferably performed at high temperatures. The influence of air stripping on the performance of the regeneration was investigated in batch experiments. In these batch experiments it was shown that the reduction of partial pressure that is caused by stripping with air has a significant influence on the success of regeneration although under the experimental conditions and at the investigated air fluxes there seems to be a marginal air flux at which further increase of air does not result in significant increase of CO_2 desorption. The working capacity as indicator for combined absorption and desorption was determined and 3.5 M K-Gly and 2 M K-Lys solutions stood out as very promising solvents. However, in stability test K-Lys solution proved to degrade under operating conditions. Thus, further investigations were restricted to K-Gly solution for the time being. Isotherms of the 3.5 M K-Gly solution were recorded over a wide range of CO_2 partial pressure in the gas phase and a continuously working lab scale plant was operated with 3.5 M K-Gly solution. It could be proven that the proposed process is applicable for continuous biogas upgrading with the regeneration of the solvent at low heat values as 80 and even 60°C. By choice of appropriate liquid to gas ratio it was able to meet the required bio-methane properties for the injection into the national gas grid while methane losses were very low. The solvent regeneration at lower heat values would facilitate the integration of the upgrading process in existing biogas plants and might be related to a reduced energy demand for biogas upgrading compared to the conventional processes, which has to be investigated in future research. Furthermore, isotherms of additional amino acid salt solutions should be investigated to be able to single out amino acid salt that may be suitable. The lab scale plant should be optimized in terms of heat losses and the process should be tested on a larger scale. Further investigations should aim for the acquisition of the relevant data that are required for process up scaling and simulation. By this means direct comparison of plant dimension and energy requirements between the investigated and conventional biogas upgrading process would be possible.

5 ACKNOWLEDGMENT

The investigations were carried out within the project "Biogasaufbereitung durch den Einsatz von Aminosäuresalzen" (Förderkennzeichen: 22002311). The authors thank the BMELV for the financial support.

6. REFERENCES

[1] Aronu, U. E., Hartono, A., Hoff, K. A., and Svendsen, H. F. 2011. Kinetics of Carbon Dioxide Absorption into Aqueous Amino Acid Salt: Potassium Salt of Sarcosine Solution. Industrial & Engineering Chemistry Research. *Ind. Eng. Chem. Res* 50, 18, 10465–10475.

[2] Astaria, G., Savage, D., and Bisio, A. 1983. *Gas treating with chemical solvents*. J. Wiley and Sons, New York.

[3] Blauwhoff, P. M. M., Versteeg, G. F., and van Swaaij, W. P. M. 1984. A study on the reaction between CO2 and alkanolamines in aqueous solutions. *Chemical Engineering Science* 39, 2, 207–225.

[4] Brouwer, J., Feron, P., and Asbroek, N. ten, Eds. 2009. *Amino-acid salts for CO2 capture from flue gases*.

[5] Goff, G. 2005. *Oxidative Degradation of Aqueous Monoethanolamine in CO2 Capture Processes: Iron and Copper Catalysis, Inhibition, and O2 Mass Transfer*. Dissertation, The University of texas at Austin.

[6] Kaltschmitt, M., Hartmann, H., and Hofbauer, H. 2009. *Energie aus Biomasse*. *Grundlagen, Techniken und Verfahren*. Springer, Berlin, Heidelberg.

[7] Klinski, S. 2006. *Studie Einspeisung von Biogas in das Erdgasnetz*. *Einspeisung von Biogas in das Erdgasnetz*. Nachwachsende-Rohstoffe.de. Fachagentur Nachwachsende Rohstoffe, Gülzow.

[8] McCann, N., Maeder, M., and Attalla, M. 2008. Simulation of Enthalpy and Capacity of CO2 Absorption by Aqueous Amine Systems. Industrial & Engineering Chemistry Research. *Ind. Eng. Chem. Res* 47, 6, 2002–2009.

[9] Reppich, M., Datzmann, S., Li, X., Rosenbauer, S., Schlecht, C., and Tschepur, S. 2009. Vergleich verschiedener Aufbereitungsverfahren von Biogas zur Einspeisung in das Erdgasnetz. *Chemie Ingenieur Technik* 81, 3, 211–223.

[10] Rochelle, G. T. 2009. Amine Scrubbing for CO2 Capture. *Science*, 325, 1652.

[11] Sattler, K. 2001. *Thermische Trennverfahren*. *Grundlagen, Auslegung, Apparate*. Wiley-VCH, Weinheim [u.a.].

[12] Smyth, B. M., Smyth, H., and Murphy, J. D. 2011. Determining the regional potential for a grass biomethane industry. *Applied Energy* 88, 6, 2037–2049.

[13] Weiland, P. 2010. Biogas production: current state and perspectives. *Appl Microbiol Biotechnol* 85, 4, 849-860.

PROCESS CHARACTERISATION OF PILOT-SCALE SYNGAS PRODUCTION VIA PRESSURISED GASIFICATION OF BIOMASS

Marklund M.[1], Weiland F.[1,2], Westerberg P.[3], Gebart R.[2] and Göktepe B.[2]*
[1]Energy Technology Centre in Piteå (ETC), Box 726, 941 28 Piteå, Sweden
[2]Division of Energy Science, Luleå University of Technology (LTU), 971 87 Luleå, Sweden
[3]BioGreen AB, Box 702, 941 28 Piteå, Sweden
**Corresponding author: magnus.marklund@etcpitea.se*

ABSTRACT: There are currently strong national needs and industrial interests in Sweden to develop the concept of Pressurised Entrained flow Biomass Gasification (PEBG) further to a viable commercial technology. In 2011, a PEBG pilot plant was commissioned at ETC, with a maximum solid biomass fuel feed of 1 MW_{th} at pressures up to 10 bar. The general objective with this plant is to make industrially relevant experiments and research to provide valuable information for the understanding and industrial deployment of auto-thermal entrained-flow biomass gasification. The current paper present an up-to-date summary of the main research and process development activities performed within this project. Based on initial data and experiences obtained from previous process verification activities, the functionality and performance of the solid fuel feeding system in the PEBG pilot plant has recently been greatly improved. As a result, successful scientific pilot experiments have provided interesting data for further development of the PEBG concept. So far, the results obtained at various operational conditions show that the C content in the syngas and soot particles are approximately 92-99 % and 0.1 % of the total ingoing C, respectively. Gases, particulates, and tars have been sampled from the hot reactor using a water-cooled and nitrogen purged dilution probe and the first results are currently being evaluated. Furthermore, an experimental laser based setup for examine physico-chemical parameters on soot formation has successfully been tested in an atmospheric entrained flow reactor similar to the PEBG gasifier.

KEYWORDS: Biomass gasification, entrained flow, process characterisation

1 INTRODUCTION

Besides electricity production, gasification can be applied for production of transportation fuels and chemicals by using the resulting syngas obtained from the gasification process of the virgin raw material in synthesis processes. Despite the maturity of coal based gasification, biomass gasification is still in its development stage where approximately 2% of the raw material used for gasification is derived from biomass. Furthermore, the majority of the biomass based installations are based on the fixed or fluidised bed technology concepts and intended for power production. However, there are currently strong national needs and industrial interests in Sweden to develop the concept of Pressurised Entrained flow Biomass Gasification (PEBG) further to a viable commercial technology, e.g. for producing transportation fuels and chemicals to mitigate the fossil dependence. The entrained flow gasification (EFG) concept is well-known from direct coal gasification and thoroughly presented in the literature, e.g. by Higman and van der Burgt [1]. Furthermore, the EFG concept for biomass is nicely reviewed in the handbook by the BTG Biomass Technology Group [2].

Since 2009, BioGreen, IVAB, Sveaskog and Smurfit Kappa as industrial partners, ETC and LTU as R&D actors, and Swedish Energy Agency as main funder have via a consortium joined forces to accelerate the development and industrial deployment of PEBG. One of the main outcomes has been a PEBG pilot plant (see schematic drawing in Figure 12) situated at ETC in Piteå, Sweden, and commissioned in 2011. The plant has a maximum fuel throughput of 1 MW_{th} at pressures up to 10 bar and is mainly designed to gasify solid biomass feedstock in slagging mode using oxygen, carbon dioxide, and steam at process temperatures between 1200 and 1500 °C. For further detailed description of the pilot plant and results obtained from gasification experiments with stem soft wood, see Weiland et al. [3]. Other relevant PEBG pilot results obtained for lignin residue and pyrolysis oil can also be found elsewhere [4], [5], and [6].

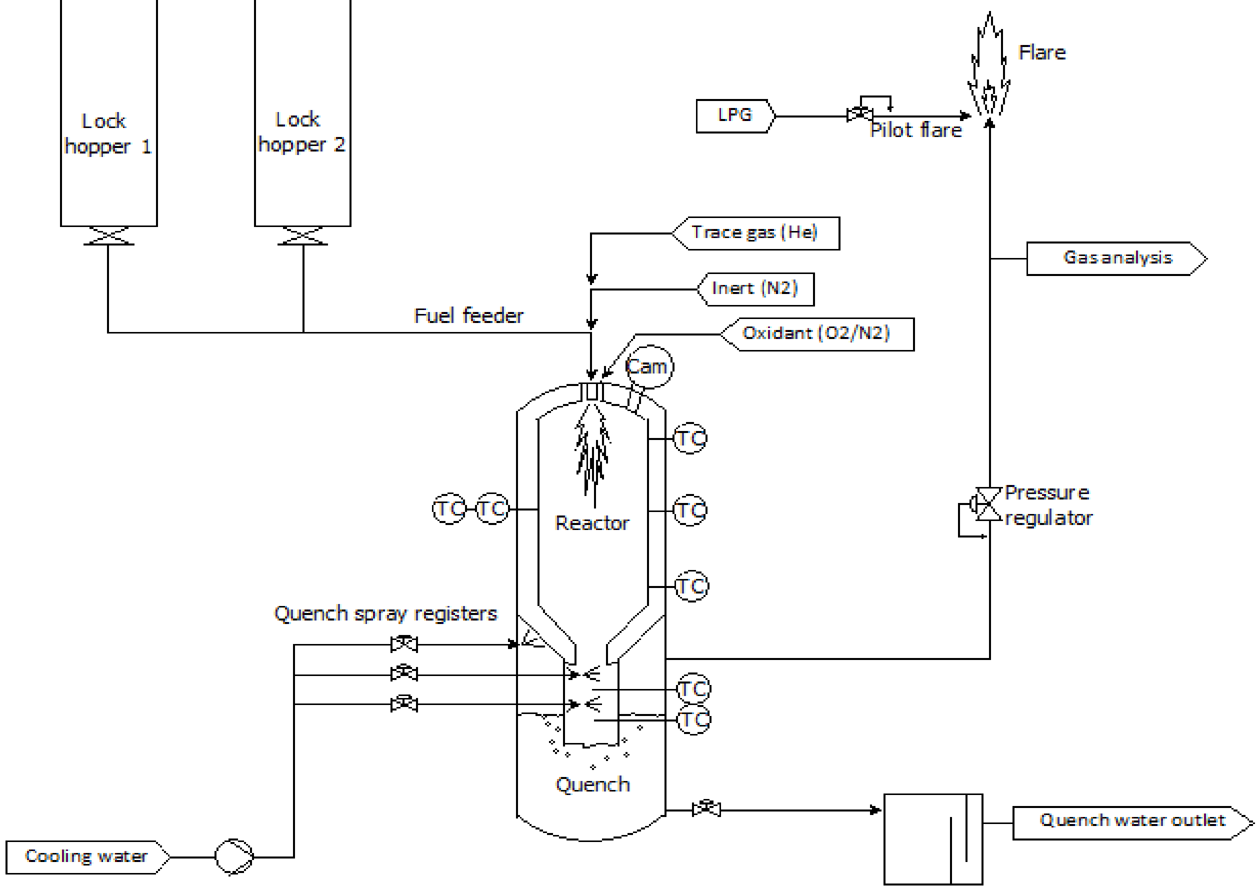


Figure 12. Schematic drawing of the PEBG pilot plant at ETC.

The general objective with the pilot plant is to make industrially relevant experiments and provide valuable information to the understanding of the auto-thermal entrained-flow biomass gasification concept. The current on-going activities are performed within a project named PEBG Characterisation and the main objective with the current paper is to give an up-to-date summary of the main research and process development activities performed within this project.

2 ON-GOING PEBG R&D ACTIVITES

The overall purpose with the current on-going activities within the PEBG Characterisation project is to perform thorough characterisation and optimisation of the available PEBG pilot plant and with the main objectives to: close the mass- and energy balances for the pilot plant; sample and analyse the product gas from the reactor; make necessary process development in order to secure stable and reliable operational performance; develop and evaluate methods for characterization of soot formation and to generalize obtained results to flames under gasification conditions. The considered general optimisation criteria for the PEBG process can be summarised as:

- Maximise process availability
- Maximise CGE with respect to considered application
- Minimize the fuel pre-treatment requirements
- Minimize soot and tar formation in reactor
- Maximize particulate separation from product gas
- Minimize needs for handling process water in the plant

The objectives with the pilot plant experiments, process development and process analysis performed in the project (as separate work packages) are to characterize and improve the PEBG process performance by contributing with thorough studies on the dependence of operational conditions on the resulting system performance for different downstream syngas applications, i.e. value chain routes. The main conceptual routes considered are: fuel gas production;

power and heat generation; and synthetic fuel applications. In general, the levels of syngas cleaning requirements for these alternatives increase in the given order of appearance (i.e. the highest syngas quality is required for the synthetic fuel application). Through evaluations of the observations and experiences gained from the trials performed in the pilot plant, continuous process development work is performed with respect to the general optimisation criteria listed above.

3 RESULTS AND DISCUSSION

In the following subsections, up-to-date results and discussions are presented from the on-going R&D activities performed within the PEBG Characterisation project.

3.1 Pilot experiments

The experimental work described below is divided into three different sub-categories; detailed mass and energy balances; hot-probe syngas sampling from inside of the reactor; and overall process characterization

3.1.1 Detailed mass and energy balances
Closing the mass and energy balance is of great importance prior to process characterization. In this work the focus was to close the main mass balances, i.e. the C, H and O balances. Therefore, all ingoing and outgoing streams, all relevant process temperatures, and other important parameters were carefully measured in a series of experiments. Furthermore, the experiments were performed at different operating conditions and the plant was operated until thermal equilibrium was reached. The inlet gas flows were monitored with mass flow controllers (MFC), the fuel feeding was controlled by a careful feeding calibration procedure (prior to the experiment), and the ingoing quench water flow was determined through standardized water flow meters. Via gas analysis with a micro gas chromatograph (µGC) of a slip stream of the resulting syngas and the use of some small amount of Helium gas (He) as a trace gas, the outlet syngas flow was determined out from the He concentration (assuming He as inert in the process). Furthermore, quench water samples were filtered and analyzed in order to find the mass flow of separated particles in the quench. Additionally, particle concentrations in the syngas were measured with a 13-stage Dekati® Low Pressure Impactor (LPI).

Typical process temperature profiles and main syngas concentrations from experiments in the PEBG pilot can be found in Figure 13.

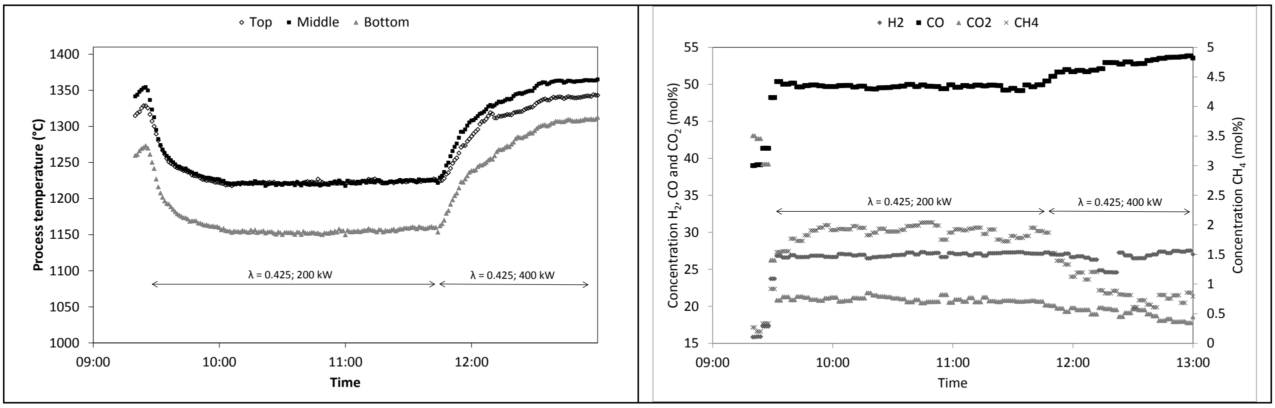


Figure 13. Typical temperature profile (left) and main syngas concentration (right).

The results obtained so far show that approximately 92-99 % of the ingoing C atoms were found in gaseous species in the syngas. Syngas soot particles contained less than 0.1 % of the ingoing C atoms. Residual C atoms were found in soot particles separated by the quench. The H and O balances were closed within ± 2 %. The major part of the ingoing H and O atoms originated from the quench water sprays. Steam generated in the gasification process was condensed in the quench and thus measured as a higher outlet water flow compared to the inlet water flow.
To this point, the energy balances for the considered experimental trials could be closed within ± 5 %.

3.1.2 Hot-probe sampling
A water cooled and nitrogen purged dilution probe was designed, constructed and operated in the PEBG plant. The gas samples withdrawn from inside the hot reactor were analyzed with gas chromatography. Furthermore, particle concentrations and size distributions were measured with Dekati® LPI and tar species were sampled using SPA (solid phase adsorption) method. The detailed results are under evaluation and will be presented in scientific journals.

3.1.3 Process characterization

The most recent, and still ongoing, work in the PEBG plant focuses on characterization of the process. A large series of experiments are being performed at different operating conditions. The parameters Oxygen equivalence ratio (λ), Thermal power, Fuel particle size and Gasification pressure are varied to map the process performance. An important response parameter is the cold gas efficiency (CGE), giving the amount of fuel energy that is converted to chemical energy in the generated syngas. Generally, a process with high concentration of CH_4 in the syngas has a higher CGE. However, in the case of synthetic fuel production mainly CO and H_2 are of interest. Therefore, we define two different CGE's; the CGE_{Power} that takes all syngas species into account and the CGE_{Fuel} that only considers the CO and H_2 species in the syngas.

Examples of gasification results at 2 barA gasification pressure and for one of the fuel particle size distributions are presented in Figure 14.

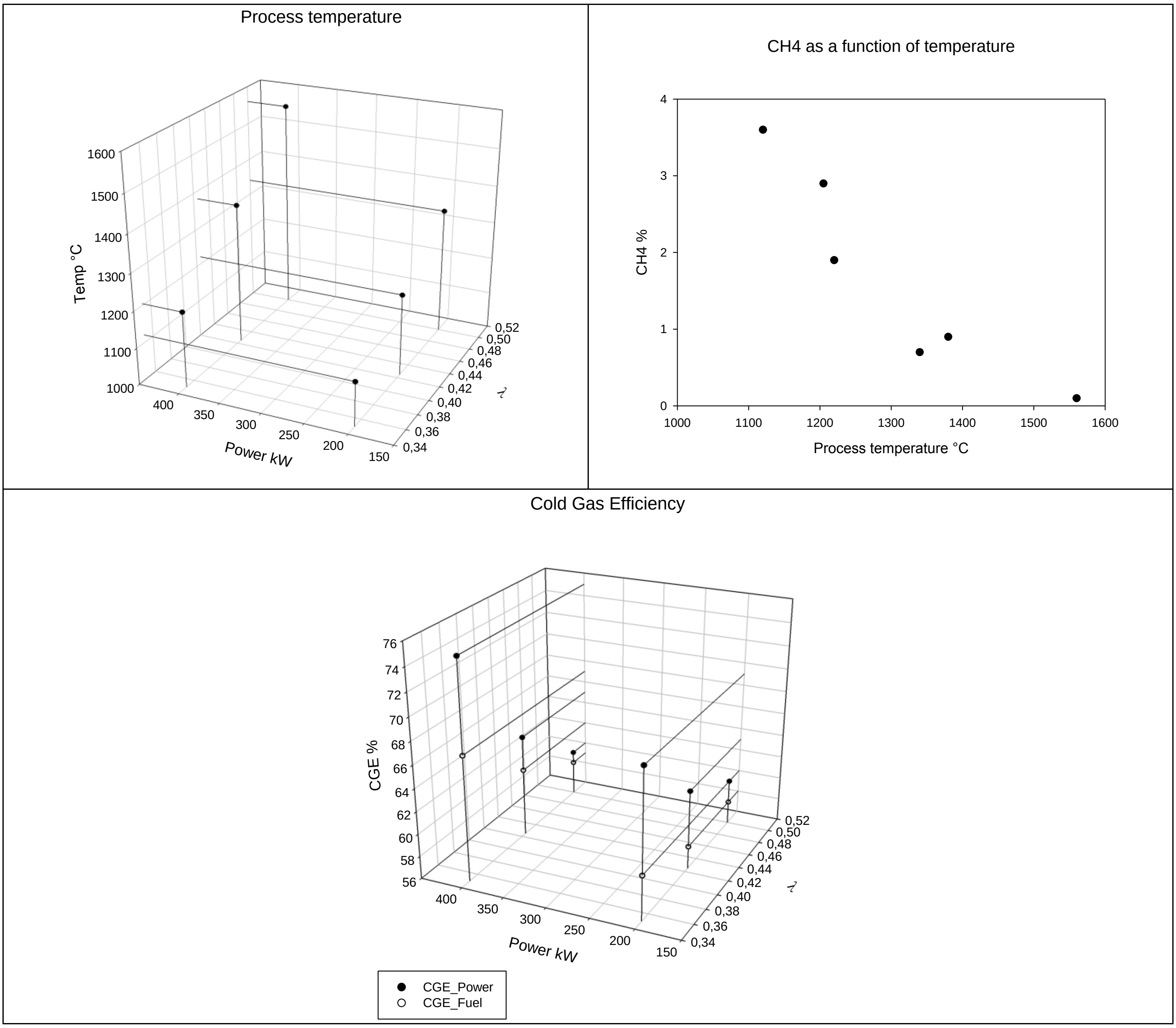


Figure 14. Process characteristics at 2 barA gasification pressure and one of the tested fuel particle size distributions.

The process temperature decreases and CGE increases at reduced λ. The difference between CGE_{Power} and CGE_{Fuel} increases as a result of increased CH_4 concentrations in the syngas. The final results will be thoroughly evaluated and published in journals when all the experiments in the experimental plan have been completed.

The syngas application and downstream syngas conditioning equipment must determine suitable operating conditions of future large scale biomass gasification plants. This ongoing work will be valuable input in the design of such a plant.

3.2 Process development

Based on initial data and experiences obtained from previous process verification activities (prior to the current PEBG Characterisation project), major reconstructions have been performed in the pilot plant. The first part consisted of improving the functionality and performance of the solid fuel feeding system resulting in major improvements, mainly regarding operational reliability and stability. Following, several improvements have been made by e.g. installing a controlled water-cooled burner; implementing additional process control features and security measures; improve camera functionality for better visibility of the fuel conversion in the reactor; and integrating flexible sampling systems in the process. As a result from the process development performed so far, the gasification experiments (see examples above) have been very successful and provided interesting data for further development of the PEBG concept (to be published).

An important part in this part of the project is to enable safe and controlled operation at higher system pressures. Trials at 5 bar pressure are currently scheduled for the second half of 2013 but before this can be done, some additional safety functionality must be added. Furthermore, more extended runs in the plant will be performed to identify critical points in the system that needs to be considered to improve the process robustness even further.

The long-term objective is to gain further experience with the concept and to optimize the plant in order to provide the basis for scale up and future deployment of the technology.

3.3 Process analysis

In order to obtain a viable PEBG technology in the long-term, there are needs for accurate and online characterization methods for process evaluations. The objective within the current Process analysis part is to gain in-depth understanding of effects of physico-chemical parameters on soot formation, such as pressure, fuel type, stoichiometry, flame lift-off length, swirl flow dynamics etc. Furthermore, methods to mitigate soot formation to reasonable levels in the PEBG gasifier will be developed. These methods will initially be based on visible light attenuation by presence of particles, where soot attenuates visible light preferentially at shorter wavelengths whereas coal, char and ash attenuate visible light equally [7].

An experimental setup with a 20 mW He-Ne dual wave length laser has been tested in an atmospheric entrained flow reactor similar to the PEBG gasifier. In this set-up, the laser light was sent across a diameter of the cylindrical reactor and the light at the other end of the diameter was successfully detected with an integrating sphere detector. The signal could then be compared to the signal when the fuel feeding was turned off (no soot) so that the corresponding soot volume fraction could be calculated in the same way as in [7]. Since the laser light is absorbed along the whole length of the diameter the resulting measurement is an integrated average of the conditions across the reactor but it is still very useful for optimisation purposes where the goal is to minimise the total amount of soot produced in the reactor. After further fine tuning of the set-up it will be installed in the pressurised PEBG reactor, to provide data about soot concentration that can further improve the understanding of the reactor characteristics and be used for optimisation of the operating conditions and the engineering design of the burner through which fuel and oxygen is fed to the reactor.

4 CONCLUDING REMARKS

There are currently strong national needs and industrial interests in Sweden to develop biomass gasification concepts further to a viable commercial technology for producing fuels and chemicals. The on-going R&D activities around the PEBG concept are driven by a consortium and a PEBG pilot plant at ETC in Piteå, Sweden, with the aim to accelerate the process development and industrial deployment. The present paper mainly presented the following up-to-date summary of the research and process development activities performed within the on-going PEBG Characterisation project:

- The results from the PEBG pilot obtained so far show that approximately 92-99 % of the ingoing C atoms were found in gaseous species in the syngas (depending on the operational condition). Soot particles in the syngas contain less than 0.1 % of the ingoing C atoms.
- To this point, the energy balances for the considered experimental trials has been been closed within ± 5 %.
- Gas samples have been withdrawn from inside the hot reactor using a water-cooled and nitrogen purged dilution probe. Furthermore, particle concentrations and size distributions were measured and tar species were sampled. The detailed results are under evaluation and will be presented in scientific journals.
- Considering variations in λ, and the process temperature, the differences between the resulting cold gas efficiencies (CGE_{Power} and CGE_{Fuel}) are clearly shown. When all the characterisation experiments in the

experimental plan have been completed (at various operational conditions), the final results will be thoroughly evaluated and published in scientific journals.
- Based on initial data and experiences obtained from previous process verification activities (at low system pressures), the functionality and performance of the solid fuel feeding system has been greatly improved.
- An experimental laser based setup for examine physico-chemical parameters on soot formation has successfully been tested in an atmospheric entrained flow reactor similar to the PEBG gasifier.
- Trials at 5 bar pressure are currently scheduled for the second half of 2013.

ACKNOWLEDGEMENTS

The current R&D project activities have not been possible without the acknowledged support from the Swedish Energy Agency, IVAB, Sveaskog, Smurfit Kappa Kraftliner, Energy Technology Centre in Piteå and Luleå University of Technology.

REFERENCES

1. Higman C, van der Burgt M (2008) *Gasification*, 2nd Edition. Oxford: Gulf Professional Publishing.
2. Knoef H (Ed.) et al. (2012) Handbook Biomass Gasification, 2nd Ed. Enschede: BTG Biomass Technology Group. ISBN: 978-90-819385-0-1.
3. Weiland F, Hedman H, Marklund M, Wiinikka H, Öhrman O, Gebart R (2013) Pressurized oxygen blown entrained-flow gasification of wood powder, Energy and Fuels 27 (2): 932–941.
4. Öhrman O.G.W, Weiland F, Pettersson E, Johansson A.C, Hedman H, Pedersen M (2013) Pressurized Oxygen Blown Entrained Flow Gasification of a Biorefinery Lignin Residue, Fuel Processing Technology 115: 130-138.
5. Gullberg M, Marklund M (2012) Spray characterization of twin fluid external mix atomization of pyrolysis oil. Atomization and Sprays 22: 897-919.
6. Öhrman et al. (2013) Pressurized Oxygen Blown Entrained Flow Gasification of Pyrolysis Oil, Proc. 21st European Biomass Conference and Exibition, June 3-7 2013, Copenhagen.
7. Stimpson C.K, Fry A, Blanc T, Tree D.R (2013) *Line of sight soot volume fraction measurements in air-and-oxy coal flames*. Proceedings of the Combustion Institute 34 (2): 2885-2893.

MAKING SYNTHETIC METHANOL FROM CELLULOSIC BIOMASS: PERFORMANCE AND COST ANALYSIS

Ilkka Hannula1, Esa Kurkela, VTT, PO Box 1000, FIN-02044 VTT, Finland, firstname.lastname@vtt.fi

The use of methanol as a motor fuel option has been discussed repeatedly since the 1920s. In the transportation sector methanol can be used by converting it first to MTBE or as direct methanol-gasoline fuel mixtures. It can also be used as a portal to hydrocarbon fuels through the conversion to dimethyl ether (DME) or gasoline (MTG), or to renewable petrochemical feedstock via the methanol-to-olefins (MTO) process. The purpose of our work was to provide improved understanding of the thermodynamic, environmental and economic performance of plants that produce synthetic methanol in large scale via fluidised-bed gasification of cellulosic biomass.

APPROACH

Steady-state mass and energy balances were calculated using Aspen Plus simulation software and detailed capital cost estimates were generated for the examined plant designs. Techno-economic assessment was carried out to identify plant configurations that exhibit most promising economics, cause minimum environmental footprint and have potential to be deployed at scale in near term. An important aspect of our analysis was to examine possibilities for overall process optimisation.

SCIENTIFIC INNOVATION AND RELEVANCE

Since 2006, VTT has been actively developing technology that enables the production of low-cost synthesis gas from biomass. A process based on pressurised fluidised-bed steam/O2-blown gasification of biomass, followed by hot-filtration and catalytic reforming of hydrocarbons and tars has been recently demonstrated at a pre-commercial scale and is ready for full-scale demonstration. Technical features of this recently proven process were incorporated into the simulation model to provide relevant up-to-date information on the feasibility of a state-of-the-art stand-alone bio-methanol plant.

RESULTS AND CONCLUSIONS

Our analysis shows that methanol can be produced from biomass with an efficiency in the range of 57.4 to 66.7 %, depending on the operating parameters of the gasification process. If the byproduct heat from the methanol plant can be sold to a near-by district heating network, the combined efficiency from biomass to methanol and heat increases to the range of 75.7 to 77.8 %, which is comparable to that of combined heat and power production. Our economic analysis further shows that it is possible to produce 100 % renewable methanol from forest residues, with a minimum levelised production cost of 64.4 €/MWh (17.9 €/GJ) without subsidies assuming Nth plant economics. We also present economic analysis on the effects of different public support mechanisms required in the realisation of the first-of-a-kind industrial plant. Methanol synthesis is commercially mature and freely available technology that is feasible in the potential size range of biomass gasification plants having a wood input of 150-300 MWth. In comparison to other synthetic fuel technologies, it demonstrates the best overall efficiency from biomass to liquid fuels and shows extremely interesting potential in the production of renewable chemicals. A biomass–to-methanol plant would therefore be an ideal way to demonstrate Finnish gasification technology and make to way for global export markets in the area of liquid biofuels and green chemicals.

HIGH PRESSURE FEED SYSTEM FOR PRESSURISED BIOMASS GASIFICATION

J. Craven, J. Swithenbank & V. Sharifi
University of Sheffield
Energy and Environmental Engineering Group (EEERG)
Department of Chemical and Biological Engineering, Mappin Street, Sheffield, S1 3JD, UK
james.craven@sheffield.ac.uk

ABSTRACT: Feeding and handling systems have been cited as one of the most common causes of process downtime in the gasification industry. Where gasifiers are operated at elevated pressure, a further layer of complexity is added as the feeding of a solid fuel has to be brought about without the loss of pressure. Current dry fed systems employed for this task are inefficient, unreliable and present a burden on the overall process. The Hydraulic Lock Hopper (HLH) looks to counter such issues and embodies a dry fed system that uses water as an incompressible fluid to bring about compression. No pressurising gas is required, so gases such as nitrogen, carbon dioxide and syngas are conserved. The HLH has showcased two modes of operation and the feeding of Ø6 mm wood pellets to pressures as high as 25 barg. Energy requirements of 15.5 kJ/kg and 20.6 kJ/kg have been recorded for Mode 1 and Mode 2, and such energy requirements demonstrate energy savings compared to conventional lock hopper systems of 82% and 76% respectively.

Keywords: Feed system, High pressure, Gasification

1 INTRODUCTION

With CO_2 emissions at an all time high and the link between carbon emissions and climate change being further compounded, the need for a sustainable and low carbon energy source has never been greater. Biomass presents an attractive option and poses as the natural replacement for conventional coal. But with coal still accounting for approximately 30% of the world's total energy supply [1], it is clear that coal will still play a significant role in the worlds energy mix for some time to come. With this in mind, a flexible technology is required, able to process both conventional and new and emerging fuels.

Gasification presents one such technology, able to handle a broad range of carbon based fuels and convert them into a flexible gaseous product – syngas. The uses of syngas are wide ranging, from the production of electricity to chemical synthesis. Methanol production from syngas presents an interesting route, as from methanol a whole host of other chemicals can be synthesised. Where biomass gasification is integrated, low carbon chemical production is enabled [2].

To maximise efficiency both in terms of electricity production and chemical synthesis, a pressurised syngas stream is required. This can be achieved via two routes. The gasifier can operate at atmospheric pressure and the syngas produced can be subsequently pressurised downstream of the gasifier, or the gasifier can operate at an increased pressure above that of the atmosphere to produce a pressurised syngas stream. It is found that the latter route requires less energy due to the large amount of energy required for syngas compression in the atmospheric case, and further to this, where the whole system operates under pressure equipment size can be vastly reduced due to increased volumetric throughput [3-5].

Operating the gasification process at an elevated pressure is clearly advantageous in terms of energy requirement. However, in order to operate the process effectively, the feeding of a solid fuel has to be brought about efficiently and without the loss of pressure. Feeding and handling systems have been cited as one of the most common causes of process downtime in the gasification industry due to the difficult nature of this task. Further to this, current dry fed systems are inefficient, unreliable and present a burden on the overall process. It is for this reason that a new feeding system for feeding solid fuels to high pressure processes must be developed.

2 HIGH PRESSURE FEED SYSTEMS

Feeding systems used to feed solid materials to high pressure processes can be split into six key categories and are highlighted in Table I [6-13]. Where high pressure gasification is concerned, lock hoppers and slurry feeders make up the majority, but the two vary dramatically from one another in how they are operated.

Lock hoppers are generally considered to be dry fed systems and are used in gasifiers that require a dry feed; gasifiers such as the Shell and Lurgi gasifier [4]. Whereas slurry feeders are wet fed systems and utilise a solid laden slurry typically made up of 60-70 wt% solids in the case of coal [7] and 10-15 wt% solids in the case of biomass [14]. Two common examples of gasifiers that utilise slurry feeders are the GE and E-Gas type gasifiers [4]. In theory, the transport medium for slurry feeders can be made up of any incompressible fluid able to be pumped; however, it is found that water is most commonly used.

Table I. Overview of high pressure solids feed systems.

Feeding System	Pressure (bar)	Advantages	Disadvantages	Reference
Rotary valve	10-12	Low energy use and capital cost	Pressure leakage, best suited to lower pressures	[8,11,13,15-16]
Lock hopper	30-90	Proven design and versatile with feedstock	High energy use and high inert gas use	[8-11,13,15, 17]
Plug-forming feeder	40-60	Proven design in paper industry	Changes material properties, high frictional wear	[8-9,13,15, 18]
Piston feeder	20-100	Low energy use and inert gas use	Low throughput, high mechanical wear	[7-9,13,15]
Dynamic feeder	10-30	Continuous operation	High energy use, complicated design	[5,9,19-20]
Slurry feeder	>100	Proven design and low energy use to feed	Large energy use to vaporise transport medium	[5,7,21-23]

Although lock hoppers and slurry feeders are widely used in industry, neither system is without its operational drawbacks. Conventional lock hoppers are typically inefficient and unreliable in the way in which they operate. They rely on large quantities of pressurised inert gas to bring about feeding, and in turn incur a large energy penalty due to the compressibility of the gas used. On top of this, the energy required to feed is almost immediately wasted during the depressurisation stage, as a lock containing a volume of gas at pressure is required to be vented in order to restart the feeding process after each batch of fuel has been fed. This constitutes the main drawback of lock hoppers and limits their use at very high pressures due to gas compression cycling becoming uneconomical [5].

Slurry feeders look to lower the energy requirement for feeding solid fuels by using an incompressible fluid. Although, slurry feeders present a low energy route for feeding, the energy requirement to vaporise the excess water fed to the system post feeding is its main drawback and leaves dry fed processes with greater overall cold gas efficiencies [4,21]. In addition to this, it can be said that the feeding of biomass fuels as a slurry is not a feasible option. This is due to biomass materials typically having low heating values and high internal moisture contents. As the moisture contained in the fuel does not go any way to make up the slurry, the overall moisture content of the biomass slurry can be said to be too high for combustion and gasification reactions to proceed effectively. Therefore, in terms of feeding biomass to pressurised processes, dry fed systems account for the majority.

3 EXPERIMENTAL PROGRAMME

The feed system developed as part of this study, named the Hydraulic Lock Hopper (HLH) looks to counter problems experienced with conventional lock hopper systems; particularly with regards to efficiency. Water is used in the compression stage of the feeding operation by displacing gas at high pressure and compressing the feedstock contained in an intermediate chamber. Due to the incompressibility of water, the compression phase can be undertaken with a significantly lower energy requirement than if gas was used to pressurise the feedstock as found in conventional lock hoppers. The only energy required for the HLH to undertake the feeding operation is by a high pressure water

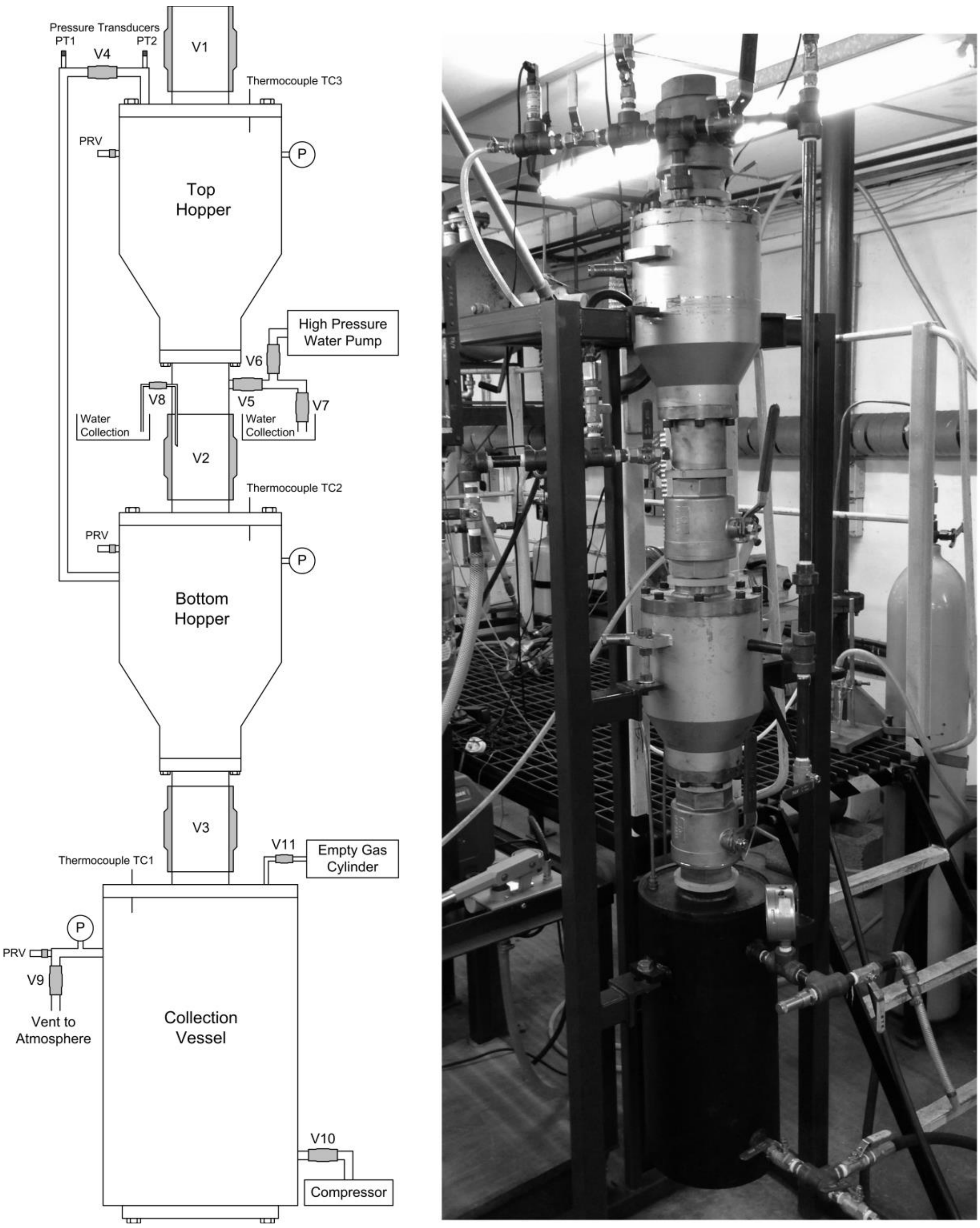


Figure 1. Schematic diagram of the Hydraulic Lock Hopper and the experimental rig.

pump used to pump water against pressure. No inert pressurising gas is required to undertake the feeding procedure, so commonly used gases such nitrogen and carbon dioxide are conserved.

The main components of the HLH are: a high pressure water pump, two hoppers equal in volume and a high pressure collection vessel. The three primary vessels (top hopper, bottom hopper and collection vessel) are separated by three inch bore ball valves and further to this an external pipe connects the two hoppers and facilitates the compression stage of the feeding operation.

3.1 Feeding procedure

The HLH can be operated in two modes. Mode 1 is less energy intensive than Mode 2 and is used where levels of lock gas contamination with syngas are low, as a portion of gas at high pressure is vented to the atmosphere after feeding has been completed. Mode 2 requires a larger amount of energy than Mode 1 but minimises the volume of gas at high pressure vented and so can be used where lock gas contamination with syngas is high.

3.1.1 Mode 1

In Mode 1 the HLH starts with all valves in the closed position, the top hopper at atmospheric pressure and both the bottom hopper and the collection vessel at the desired operating pressure. Fuel is fed to the top hopper and the top hopper is sealed. V2 and V4 are opened allowing fuel to bed fed to the bottom hopper and pressure equalisation between the top and bottom hopper to take place. The high pressure water pump is turned on and water is pumped to the top hopper which in turn compresses the fuel contained in the bottom hopper via the external pipe. The volume of water required to be fed in this stage is approximately equal to the void space present between the fuel. Therefore, after the compression stage has been completed, there is a head space above the water level in the top hopper that is also at pressure. V4 is closed and V3 is opened which allows fuel to be fed to the high pressure collection vessel with no net change in pressure. Water is then drained from the top hopper by utilising the pressure difference between the atmosphere and the pressure of the gas contained above the water level.

3.1.2 Mode 2

The operational procedure for Mode 2 is broadly similar to Mode 1; however, V3 is left in the open position at all times. After pressure equalisation through the opening of V2 and V4, a volume of water equal to the volume of the top hopper is required to be pumped. This displaces all of the gas at pressure and effectively minimises the volume of gas at pressure vented during the water drainage stage. Due to the volume of the fuel fed, a slight net pressure increase in the collection vessel is recorded during operation in Mode 2.

4 RESULTS AND DISCUSSION

In its current form the HLH operates as a batch process. Continuous feeding can be enabled through the implementation of atmospheric systems downstream, systems such as metering bins and screw feeders; however, in this case batch feeding is only enabled. The feeding operation was initially demonstrated using 4 kg batches of wood pellets, feeding against back pressures of up 25 barg. The power drawn by the high pressure pump was recorded along with the time taken to feed and in turn the energy requirement of the HLH was assessed per unit mass of fuel fed. Figure 2 highlights the energy use per unit mass of the HLH operating in Mode 1 and Mode 2.

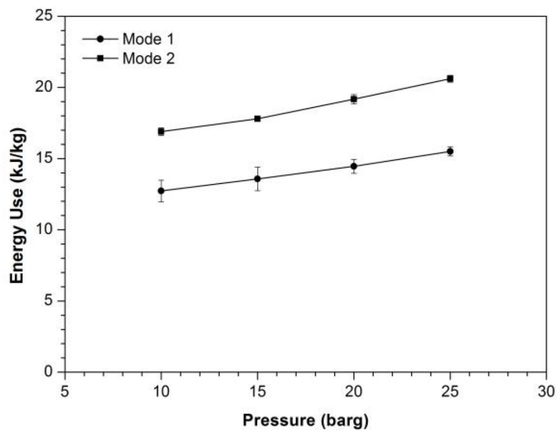


Figure 2. Energy use of the HLH operating in Mode 1 and Mode 2.

A general trend of increasing energy use with increasing pressure for both modes of operation can be seen in Figure 2. Further to this, Mode 1 is observed to require less energy than Mode 2 at all operating pressures. This is simply due to the volume of water required to be fed in the compression stage of the feeding operation. Mode 1 requires a volume of water to be fed that is approximately equal to the fuel voidage. In this case a 4 kg batch of wood pellets has a voidage of approximately 61%; this is inclusive of the head space above the fuel level and the volume due to pipe work/fittings. In the case of Mode 2 the volume of water pumped is ideally equal to 100% - the volume of the top hopper. However, this figure is impractical, not least due to the likelihood of water carry over into the bottom hopper/collection vessel. Therefore, a predetermined volume of water (7500 ml) to be pumped is set in this case, which corresponds to approximately 88% of the volume of the top hopper (8520 ml). This makes sure no water is carried over and in turn ensures that the physical stability of the material is maintained.

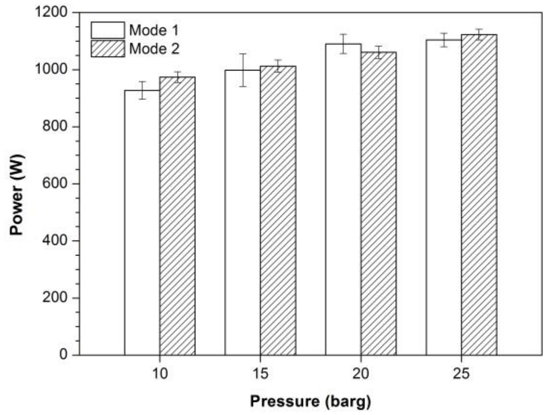


Figure 3. Power drawn by the high pressure water pump operating in Mode 1 and Mode 2.

Reviewing the results shown in Figure 3 it can be seen that the power drawn by the high pressure water pump is variable and increases with increasing pressure. Combining such results with those shown in Figure 2 for energy use indicates a constant compression time independent of pressure. The compression phase of the feeding operation is the main variable of the system, and therefore as compression time is seen to stay broadly constant with increasing pressure, the mass flow rate is also seen to stay broadly constant with increasing pressure.

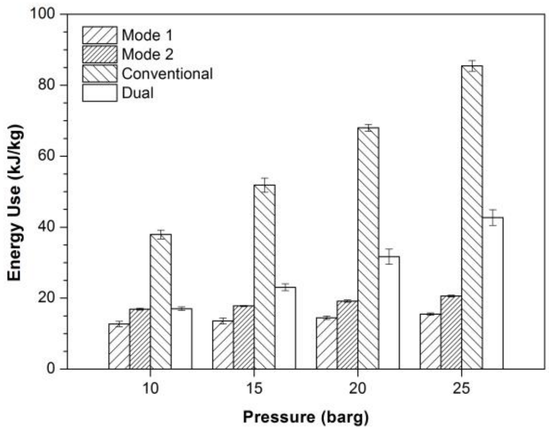


Figure 4. Energy use of the HLH compared to a conventional single and dual lock hopper.

Further to operation in Mode 1 and Mode 2, the HLH was operated as a conventional single and dual lock hopper using a three-stage compressor. The power drawn and compression time were recorded and in turn the energy requirement per unit mass of fuel fed was assessed. Figure 4 displays the results relating to energy use per unit mass of fuel fed. It can be seen that both a conventional single and dual lock hopper require a greater amount of energy to feed than the HLH operating in either Mode 1 or Mode 2 at all operating pressures. Mode 1 shows a clear advantage over both conventional systems at all pressures recorded, whereas as pressure is decreased to approximately 10 barg, a dual lock hopper is seen to become competitive with the HLH operating in Mode 2. However, as pressure is increased, Mode 2 is seen to achieve significant energy savings over both a conventional single and dual lock hopper.

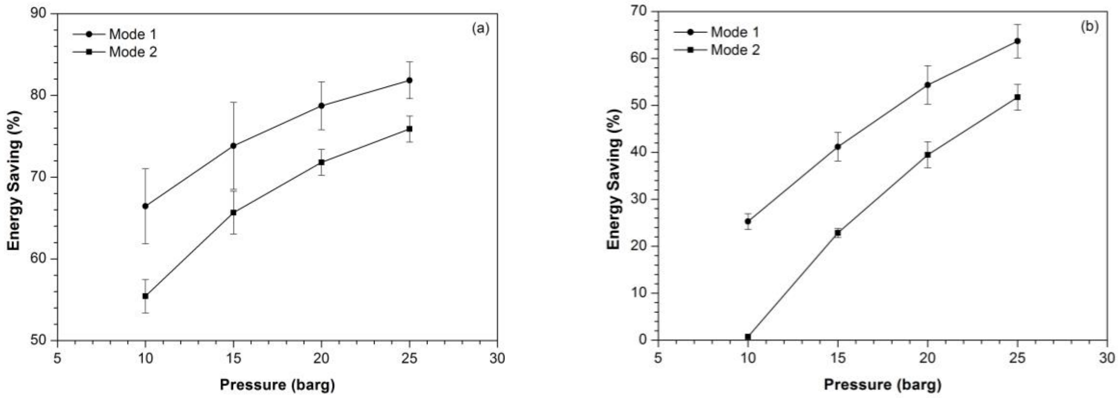


Figure 5. Energy saving generated by the HLH compared to a conventional single lock hopper (a) and a dual lock hopper (b).

When viewing the energy use of the HLH alongside both a conventional single and dual lock hopper, it can be seen that significant energy savings are generated. Figure 5 (a) and (b) show general increasing trends of energy saving with increasing operating pressure for both modes of operation and compared to both a conventional single and dual lock hopper respectively. It is indicated in both Figure 5 (a) and (b) that an upper limit of approximately 85-95% is achievable as pressure is increased further.

5 INDUSTRIAL APPLICATION

Gasification potentially poses as one of the major cornerstones of modern power generation and chemical synthesis. It is with this in mind that a wide range of industries can benefit from the use of the HLH in place of conventional lock hoppers. Since the energy requirement to feed is stated in terms of energy per unit mass, it is convenient to assess the energy use in relation to the calorific value of the fuel being fed. Taking an average biomass fuel with a higher heating value (HHV) of 18.90 MJ/kg [24], it can be seen that the HLH operating in Mode 1 and Mode 2 corresponds to approximately 0.082% and 0.11% of the HHV respectively. Similarly, taking an average bituminous coal with a HHV of 32 MJ/kg [5], it can be seen that the HLH operating in Mode 1 and Mode 2 corresponds to approximately 0.048% and 0.064% of the HHV respectively.

Table II. Energy, mass, CO_2 and cost savings generated by the HLH in a 1 GW gasification plant.

	Bituminous Coal		**Average Biomass**	
Saving (per Day)	**Mode 1**	**Mode 2**	**Mode 1**	**Mode 2**
Energy (MWh)	109	101	186	172
Mass (Tonnes)	26	24	74	68
CO_2 (Tonnes)	73	68	130	120
Cost (£)	9,084	8,421	15,442	14,316

Table II highlights the potential savings generated by the HLH operating at 25 barg in Mode 1 and Mode 2 compared to a conventional single lock hopper. The values stated assume a gasification plant with a power rating of 1 GW operating with an overall efficiency of 48% (Cold Gas Efficiency = 81%) [5]. Values relating to energy and cost savings are through savings in electricity, assuming an average price of 8.31 pence/kWh [25]. Comparatively to this, values relating to mass savings assume electricity is generated on site and therefore translate to the extra mass of fuel required to be processed by a plant using a conventional lock hopper. Further to this, CO_2 savings assume a fixed carbon content of 48 wt% [24] for biomass and 78 wt% [5] for coal.

In addition to the savings stated, a further advantage of the HLH over competing high pressure feed systems is that the HLH can be retrofitted to existing lock hoppers at a relatively low cost. The only equipment required in addition to the existing lock hopper is high pressure pipe work and a high pressure water pump. Given the stated financial savings, it is envisaged that the HLH can be implemented with a relatively short payback period.

6 CONCLUSIONS

This study has showcased the development of the Hydraulic Lock Hopper (HLH), a new feed system for feeding solid fuels to high pressure gasifiers. The HLH has demonstrated the feeding of Ø6 mm wood pellets against back pressures of up to 25 barg in two modes of operation. Energy requirements per unit mass of 15.5 kJ/kg and 20.6 kJ/kg have been recorded for operation in Mode 1 and Mode 2 at 25 barg. Such energy requirements translate to energy savings compared to a conventional single lock hopper of the same magnitude of 82% (Mode 1) and 76% (Mode 2). Similarly, such energy requirements translate to energy savings compared to a dual lock hopper of 64% (Mode 1) and 52% (Mode 2). Further to this, the compression time for the HLH has been shown to take place independently of pressure, and in turn the mass flow rate through the HLH has also been shown to take place independently of pressure.

7 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Biomass and Fossil Fuels Research Alliance (BF2RA) and the Engineering and Physical Sciences Research Council (EPSRC) for their financial support. Thanks go to Greg Kelsall (BF2RA), Dr David Peralta-Solorio (E.ON) and Peter Sage (BF2RA) for their technical support, and special thanks go to Mike O'Meara and David Palmer (University of Sheffield) for their assistance in the manufacture of the experimental rig.

8 REFERENCES

[1] BP 2013. BP Statistical Review of World Energy June 2013. BP, London.

[2] Spath, P. L. & Dayton, D. C. 2003. Preliminary Screening - Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas. US-DOE, National Renewable Energy Laboratory.

[3] Boerrigter, H. & Rauch, R. 2006. Review of Applications of Gases from Biomass Gasification. ECN Biomass, Coal and Environmental Research, Holland.

[4] Phillips, J. 2006. Different Types of Gasifiers and their Integration with Gas Turbines. Electric Power Research Institute, Advanced Coal Generation.

[5] Higman, C. & Van der Burgt, M. 2008. Gasification, Gulf Professional Publishing.

[6] Jet Propulsion Laboratory. 1977. Proceedings of the Conference on Coal Feeding Systems. U.S. Energy Research and Development Administration, California Institute of Technology, Pasadena, California.

[7] Hawrych, J. R. 1981. High Pressure Coal Feeding Systems for Coal Conversion Plants. International Gas Research Conference. Worley Engineering Limited.

[8] Levelton, B. H. 1982. Status of Biomass Feeder Technology, Canadian Forestry Service.

[9] Guzdar, A. R. & Harvey, A. C. 1982. Feeding Coal and Biomass into High Pressure Reactors. Biomass to Methanol: A Specialists' Workshop. US-DOE, Tamarron, Durango, Colorado.

[10] Rautalin, A. & Wilén, C. 1992. Feeding Biomass into Pressure and Related Safety Engineering, Technical Research Centre of Finland (VTT).

[11] Wilén, C. & Rautalin, A. 1993. Handling and Feeding of Biomass to Pressurized Reactors: Safety Engineering. Bioresource Technology, 46, 77-85.

[12] Cummer, K. R. & Brown, R. C. 2002. Ancillary Equipment for Biomass Gasification. Biomass and Bioenergy, 23, 113-128.

[13] Swanson, M. L., Musich, M. A., Schmidt, D. D. & Schultz, J. K. 2003. Feed System Innovation for Gasification of Locally Economical Alternative Fuels (FIGLEAF). DOE No. DE-FC26-00NT40904. US-DOE, National Energy Technology Laboratory, Pittsburgh.

[14] Berglin, E. J., Enderlin, C. W. & Schmidt, A. J. 2012. Review and Assessment of Commercial Vendors/Options for Feeding and Pumping Biomass Slurries for Hydrothermal Liquefaction. US-DOE, Pacific Northwest National Laboratory.

[15] Lau, F. S., Bowen, D. A., Dihu, R., Doong, S., Hughes, E. E., Remick, R., Slimane, R., Turn, S. Q. & Zabransky, R. 2002. Techno-economic Analysis of Hydrogen Production by Gasification of Biomass. US-DOE, National Renewable Energy Laboratory, DE-FC36-01GO11089.

[16] Grace, T. M., Malcolm, E. W. & Kocurek, M. J. 1989. Pulp and Paper Manufacture - Volume 5: Alkaline Pulping.

[17] Knoef, H. A. M. & Vis, M. W. 2001. State of the Art of Feeding Systems for Biomass Gasifiers. Enschede: BTG Biomass Technology Group BV.

[18] Schell, D. 1988. High Pressure Solids Feeding using a Lockhopper System: Design and Operating Experience. Applied Biochemistry and Biotechnology, 17, 73-87.

[19] Combustion Engineering Inc. 1994. CE IGCC Repowering Project: Use of the Lockheed Kinetic Extruder for coal feeding. US- DOE, Office of Fossil Energy, Windsor, Connecticut.

[20] Van der Burgt, M. J. 1982. Method and Device for the Feeding of Finely Divided Solid Matter to a Gas-containing Vessel. U.S. patent application 4,360,306.

[21] Gall, R. L. & Johnson, E. K. 1983. An Overview of Coal-feed Systems. Chemical Engineering Progress, 79, 31-36.

[22] Funk, E. D. 1983. Continuous Feeding of Coal to Pressurized Systems. Chemical Engineering Progress, 79, 37-41.

[23] Ferretti, E. J. 1974. Feeding Coal to Pressurized Systems. Chemical Engineering (New York), 81, 113-116.

[24] Neves, D., Thunman, H., Matos, A., Tarelho, L. & Gómez-Barea, A. 2011. Characterization and Prediction of Biomass Pyrolysis Products. Progress in Energy and Combustion Science, 37, 611-630.

[25] DECC 2013. Quarterly Energy Prices: June 2013. Department of Energy and Climate Change, London.

JATROPHA BIO-DIESEL PRODUCTION TECHNOLOGIES

Ebtisam Heikal, Egyptian Petroleum Research Institute (EPRI), Egypt

Abstract.

The interest in using Jatropha Curcas L. (JCL) as a feedstock for the production of bio-diesel is rapidly growing. The properties of the crop and its oil have persuaded investors and policy makers consider JCL as a substitute for fossil fuels to reduce greenhouse gas emissions.

In this paper, we give an overview of the currently available information on the different process steps of the production process of bio-diesel from JCL.

Based on this collection of data and information the best available practice, the shortcomings and the potential environmental risks and benefits are discussed for each production step. The paper concludes with a call for general precaution and for science to be applied.

Conclusions and Suggestions

I- **JCL oil chemistry**

Some of the properties of JCL oils produced from different species are more or less the same, while others are widely variable.

The FFA$^{\underline{S}}$ (Free Fatty Acids) content of the oil is one of the variable properties which should be given paramount retention, since it decides the FAME (Fatty Acid Methyl Esters) production scheme and the economics of the process.

II- **JCL FAME Production**

At present, the most widely used technology for FAME production is the homogeneous alkali catalysed process.

Yet, from between the technologies under development and those which have entered commercial application, two new technologies, namely, the super critical

(SC) non-catalytic TE (Trans Estrification), and the newly developed heterogeneous solid catalyst process, capture interest.

Yet, the SC transesterification process has been in commercial application, mainly in Germany, long before the introduction of the heterogeneous solid catalyst technology.

Suggested R&D studies

- Further studies of the reaction kinetics and optimization of the process variables, namely, the temperature and pressure may greatly improve the economics of the SC non-catalytic TE technology.
- Since the heterogeneous solid catalyst technology depends mainly upon the catalyst and the controversial statements about the effects of FFA$^{\underline{S}}$ and water contents of the feed oil on the catalyst activity, it is recommended to support research work and development studies on the production of prospective solid catalysts for TE of vegetable oils.

ABLATIVE FAST PYROLYSIS - POTENTIAL FOR COST-EFFECTIVE CONVERSION OF AGRICULTURAL RESIDUES

A. Apfelbacher, R. Bertling, S. Conrad and T. Schulzke
Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT,
Division Processes, Department Biorefinery/Biofuels, Group Thermochemical Conversion
Osterfelder Strasse 3, 46047 Oberhausen, Germany
E-Mail andreas.apfelbacher@umsicht.fraunhofer.de

ABSTRACT: The major parameter for the profitability or economic viability of biomass pyrolysis plants is the cost of the feedstock used in the process. Economic studies have proven, that costs for the logistics chain play a dominant role within the feedstock costs for e.g. agricultural crop residues (like straw) or forest residues. Avoiding these logistic cost will lead to a far more economic biomass pyrolysis process. In order to reach this aim, a mobile biomass pyrolysis plant, operating on the agricultural fields, will be constructed and tested within the Fraunhofer Innovation-cluster »Bioenergy«, partly funded by the state Northrhine-Westfalia and the Fraunhofer Gesellschaft established at Fraunhofer UMSICHT in Oberhausen, Germany. In the first stage ablative fast pyrolysis plants have been installed in laboratory- and demonstration scale to investigate and prove the feasibility of the ablative fast pyrolysis of agricultural biomass residues. The concept consists out of energy autarkic on site fast pyrolysis, using the pyrolysis gases produced as process heat resource.

Economical calculation demonstrates the financial benefit of mobile pyrolysis plants compared to stationary plants. Mobile on site ablative fast pyrolysis is able to generate pyrolysis liquids having production costs of approximately 20€/MWh - almost half the price of fossil fuel. Sensitivity analysis shows, that the yield of the pyrolysis liquids, the hourly throughput and the yearly operation hours dominate the influence on the production costs for pyrolysis liquids.

1 INTRODUCTION

The use of biomass as an energetic resource or as a chemical resource is of high economical and ecological relevance for the future development of Europe. Beside the classical use of wood, straw and other agricultural wastes are of high interest. In terms of its use as an energy resource or chemical resource this bio products are a certain challenge in processing and engineering. The used techniques and solutions must be reasonable concerning economical and ecological aspects. Pyrolysis of biomass is a first step in the generation of raw material with high energy content for further usage like gasification and fuel synthesis via Fischer-Tropsch synthesis, respectively. The usage of biomass as an energy resource is always in competition to the traditional arable food production, therefore the utilisation of agricultural waste streams like straw or husk are the favoured strategies for the bioenergy sector, thus the number of waste-to-energy projects increases permanently [1,2].

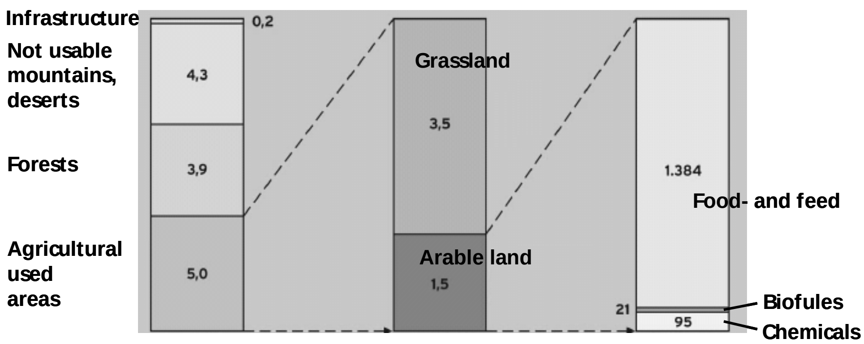


Figure.1. Worldwide landuse [3]

As Figure 1 shows, about one third of the land area of the world is used for agricultural purposes where one third of this agricultural land is used as arable land mainly for food production. An increasing population and increasing living conditions of the world population inhibit a change of the existing food production dominated landuse to a (bio) fuel generation driven landuse. Contrariwise, the increasing world population will demand more land for cities and food or fodder production. Due to this fact, future bioenergy industry has to focus on the utilization of food- or agricultural waste streams for energetic conversion. On the basis of this background, Fraunhofer UMSICHT has established the Fraunhofer Innovation-cluster »Bioenergy«.

Together with industrial partners from agriculture, food industry and chemical engineering as well as with collaborative partners from other research institutes, Fraunhofer UMSICHT will offer solutions for the physical and thermochemical exploitation of agricultural waste streams like straw or husk for renewable energy generation.

2. THE FRAUNHOFER INNOVATION-CLUSTER »BIOENERGY«

2.1 Thematic structure of the Fraunhofer Innovation cluster »Bioenergy«

The Fraunhofer Innovation cluster »Bioenergy« consists out of four main pillars, all dealing with the valorization or upgrade of agricultural waste streams or residues from grassland to biogenic energy carriers or chemical compounds. The first main pillar or lighthouse project L1 will deliver solutions for the application of wet biomass like grass for thermal conversion technologies. The core process is a mechanical dewatering process of the dry biomass where an aqueous protein solution and dry biomass is produced. The dry biomass is than suitable for a following thermal conversion process, while the aqueous protein solution can be applied to chemical extraction or can be used as fodder additive.

Main pillar L2, which is the core topic of this paper, investigates the thermal conversion of dry agricultural waste streams like straw or husk to liquid and gaseous energy carries by pyrolysis. The final aim is to develop a mobile pyrolysis unit operating directly on the agricultural fields.

Project L3 applies the hydrothermal carbonization to wet biogenic residues from food and fodder production processes like pericarp, press cake of oil seeds, rejected material, leaves, etc. and solid residues from anaerobic digestion. Hydrothermal carbonization generates a char and an aqueous solution. The so called HTC coal is suitable as carbon neutral fuel or for chemical processes.

The main duty of the pillar L4 is the commercialization of the products generated within L1 to L3 including post-processing and marketing of the primary products. Commercial applications for the squeezed juice (aqueous solution in L1), pyrolysis oil (generated in L2) and biochar (L2) as well as for the HTC coal produced within L3, were worked out and were evaluated. The different possible applications for the products are shown in figure 2.

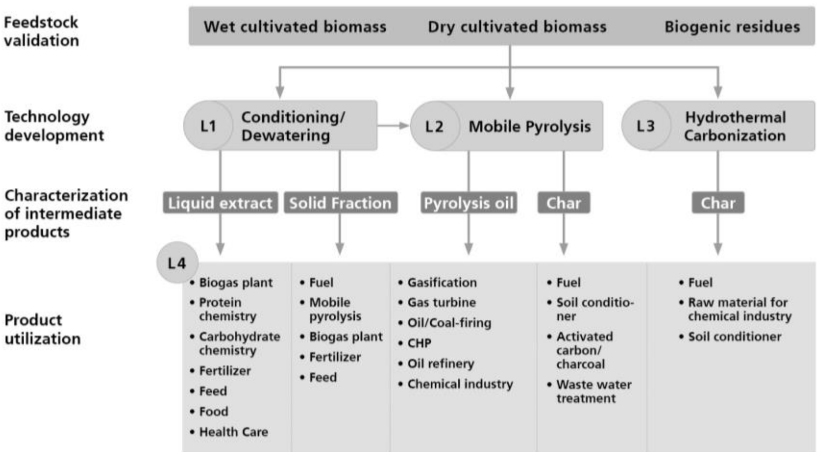


Figure 2. The Fraunhofer Innovation-cluster »Bioenergy« and its lighthouse projects L1 to L4

2.2 The mobile ablative flash pyrolysis (AFP) plant - economic justification of the mobile process

Agricultural residues as straw husk or even hay show properties like low energy densities and high ash content limiting its usability in thermal applications like combustion- or gasification processes. The harvest procedure for these kinds of residues is like the following: Straw or hay is grabbed, baled and afterwards transported to a storage unit in open or covered facilities from where it is being transported to conversion plants as required. This removal of the biomass includes a depletion of the minerals of the soils as these minerals are removed as integral part of the biomass. These minerals have to be replaced by fertilizer. In terms of economic calculation the cost for the additional fertilizer demand in case the straw is removed from the soil is the minimum price for the straw. Additional benefits by ploughing the straw like Humus generation are neglected. Due to this anticipation, the value of straw on the field is equal to the costs of the additional fertilizer demand which is around 20 € per ton of straw compared to the marked price of straw or about 100 € per ton or above [4]. Economic analysis have shown that the biggest part of the market price for straw is due to logistic effort. Figure 3 explains the origin of the price for straw in detail. One can easily figure out, that the biggest part of the costs (40 %) is generated by the work and time intensive baling process, while further 9 % are due to the transportation of the straw. A further 29 % is caused by the indoor storage of straw.

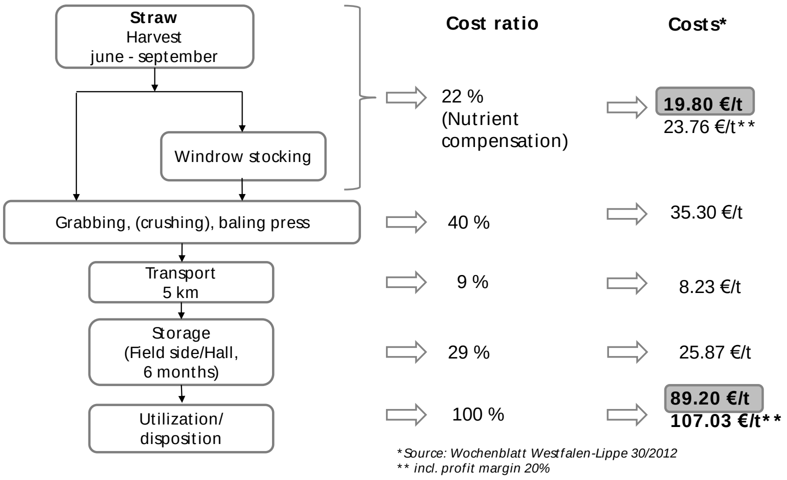


Figure 3. Breakdown of the price of straw

It is obvious that the biggest amount (around 80 %) of the straw price is caused by the logistic cost like baling, transport and storage, while only 20 % of the costs are for the fertilizer equivalent of the biomass matter itself. To improve the economy of bioenergy conversion processes, it is important to minimize the costs for feedstock. As demonstrated above, the logistic costs for straw are about 80 % of the overall straw costs. These costs could be saved if processes could be applied, which convert the straw directly onsite to generate valuable intermediate products. The generated products must therefore have a high (energy) density and must be easily transportable. This requirement of the products limits the applicable technologies. Neither combustion, which produces heat, nor gasification, which produces gases are applicable. The products generated need to be in liquid or solid state und must have a certain, high energy density. The favored technology applicable to the described scenario is pyrolysis. Pyrolysis is a process where e.g. biomass is thermally converted under the absence of oxygen at around 500 °C to (50 to 75 %) liquid, (15 to 30 %) char, consisting out of carbon and the minerals of the biomass and so called pyrolysis gases (10 to 20 %) mainly CO and CO_2. The pyrolysis liquid generated is the main product and the desired compound of the process. The pyrolysis gases are meant to be combusted to deliver the heat for the thermal conversion. The pyrolysis char can be used for co-combustion in coal power plants as renewable fuel, while the pyrolysis oil, a pumpable liquid with a high energy density, will be transported to central conversion plants as shown in figure 4.

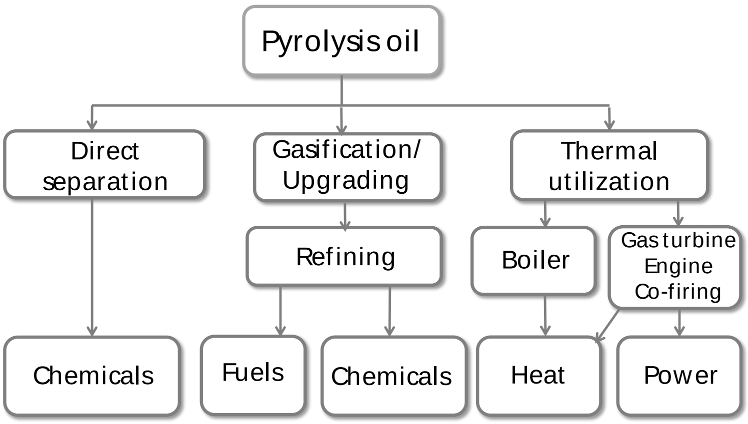


Figure 4. Possible applications for pyrolysis liquids

Today, several different pyrolysis techniques are available. The chosen pyrolysis technology has to fulfill the required specifications for a mobile on field pyrolysis unit. For instance, the reactor must fit onto a conventional agricultural vehicle in terms of size and weight. Furthermore it must be able to process a certain amount of straw comparable to an hourly throughput of a harvester. In addition the pyrolysis plant must be able to process the straw as it is left from the harvester in terms of size and lumpiness to avoid further, expensive treatment steps making the overall process weaker in its advantageous economy. For pyrolysis, fluidized bed reactors are one common technology of choice. But, as the feedstock applied for fluidized bed must be grinded, this technology is not suitable for a mobile on field pyrolysis. The same is fact for rotating cone reactors or vortex reactors. The slow pyrolysis technology is not applicable, as slow pyrolysis generally generates only small amounts of liquids while the amount of charcoal produced is maximized. Considering these fact, ablative fast pyrolysis is the best suitable technology for a mobile on field straw pyrolysis unit.

3. THE PRINCIPLE OF ABLATIVE FAST PYROLYSIS (AFP)

Ablative pyrolysis has been developed by J. Lédé in the early 1980s [4]. Compared to common fast pyrolysis techniques like fluidized bed pyrolysis, the ablative fast pyrolysis process is consuming less energy as there is no need for moving a heat carrier or a fluidization medium e.g. a sand bed. Compared to a fluidized bed, the technological and constructive effort is lower, which means the plants are generally lower in investment. An additional advantage of AFP is the ability to process lumpy feedstock saving additional pretreatment steps. The working principle shown in figure 4 is based on the idea of “melting” a solid biomass onto a hot surface, similar like butter in a pan. The produced pyrolysis liquids have to evaporate from the hot surface consuming evaporation energy. The solid biomass has to move permanently onto the hot surface in order to support the evaporation process and to inhibit the formation of an insulating char layer between the hot surface and the biomass. Due to the formation of a layer of pyrolysis liquid onto the hot surface the friction is limited, therefore saving energy. The fundamental principles of the AFP have been investigated in detail by J: Lédé. Based on his results, first AFP reactors have be constructed and have been tested successfully [5,6,7].

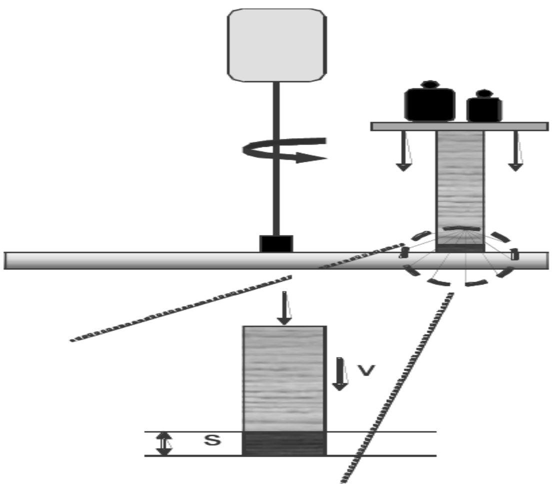


Figure 5. Principle of ablative fast pyrolysis [4]

At Fraunhofer UMSICHT in Oberhausen, Germany two AFP reactors (figure 5) of different sizes have been purchased. The principle feasibility of the AFP and its transferability to a mobile application is investigated and evaluated with the help of these units. A laboratory scale unit from PYTRADE GmbH, Hamburg, with a throughput of 10 kg/h and a 100 kg/h pilot plant from Claas Fertigungstechnik GmbH, Beelen are used for research purpose and for testing the AFP technology. The lab unit is used for fundamental scientific experiments. It is equipped with a hot rotating plate where the biomass is pressed against with hydraulic cylinders. The working principle is similar to the reactor developed by J: Lédé. Different types of biomass like wood, straw, miscanthus or bagasse are investigated towards their product distribution and their applicability for AFP. The 100 kg/h pilot plant consists out of a heated rotating drum where the biomass, favorably straw, is pressed against by conical feeding screws. The pyrolysis plant is meant to be heated by the produced pyrolysis gases and partly by the pyrolysis char. The pyrolysis vapors are liquefied in a condensation unit where several upgrade techniques can be applied to improve or adjust the quality of the pyrolysis liquids to following conversion technologies like gasification, heat and power generation by internal combustion engines or by gas turbines.

Figure 6. Laboratory and pilot scale AFP plants at Fraunhofer UMSICHT

4. ECONOMIC EVALUATION FOR THE MOBILE ABLATIVE PYROLYSIS SCENARIO

Beside the technical realization of the mobile ablative pyrolysis unit itself, the economic consideration is an important pillar of lighthouse project L2. The general requirements have been defined by Claas Group as the following: The mobile ablative pyrolysis unit shall target an hourly throughput of around 10 tons with an overall price of round about 1 million Euro per pyrolysis plant. Pyrolysis product yields are based on literature values for straw pyrolysis of 60 wt% liquid, 20 % pyrolysis char and 20 % permanent gases [8]. For the economic calculations, operation hours of only 1120 hours per year are considered, which is an average operation period for agricultural sessional deployed harvester in Germany [4]. The operation costs per hour were calculated in accordance to VDI Guideline 6025 [8]. Based on these calculations, the cost per ton of pyrolysis liquid and the costs per MWh of pyrolysis liquid have been estimated with the help of literature values for straw pyrolysis to generate comparable numbers to fossil fuels [8] (for heating oil 80 to 90 €/MWh and for heating gas 70 €/MWh are average values for 2013 for Germany [10]).
To calculate the overall production cost of pyrolysis liquid, according to VDI Guideline 6025 the Capital cost Θ_{Ca} = 143.78 €/h, Feedstock cost Θ_F = 237.60 €/h, other Consumption-related cost Θ_{Co} = 209.58 €/h, operation-related cost Θ_{Op} = 28.39 €/h, other cost Θ_O = 8.93 €/h where added up, resulting in the Production cost of Θ_P = 628.28 €/h. Assuming a throughput of 10 t/h of straw and a conversion ratio of 60 % for pyrolysis liquids, production costs of 104.71 €/t pyrolysis liquid were calculated. The average heating value for pyrolysis liquids from straw is around 4.4 MWh per ton; considering this number, results in production costs of 23.58 €/MWh for pyrolysis liquids generated from straw by a mobile on site pyrolysis plant. This calculation demonstrates, that the on site pyrolysis of straw- even only operated for 1120 hours per year- is strongly competitive to fossil energy carriers like heating oil or gas.

5 SENSITIVITY ANALYSIS OF THE MOBILE ON SITE PYROLYSIS CASE

A graph of the sensitivity analysis is shown in figure 7 [3]. It is evident, that the dominating impact to the production costs is governed by the yield of the pyrolysis liquids. It can be easily seen, that lowering the pyrolysis liquid yield by a factor of one half lead to reduplication of the costs for pyrolysis liquids. The hourly capacity, as well as the yearly operation hours of the plant contribute significantly to the sensitivity of the economy as well. Reduction of the hourly capacity or the yearly operation hours of the plant results in an increase of the production cost to almost 150 % or 135 % of the former price.

The yield of the pyrolysis liquids is more or less a fixed number for a certain pyrolysis temperature. For pyrolysis temperature of around 500 to 550 °C it is more or less constant at around 55 to 60 % and cannot be influenced significantly. The main tool to improve the economy of the process is to increase the yearly operation hours of the mobile pyrolysis plant. As stated above, the yearly operational hours of the plant are assumed to be 1120 hours. This is approximately one fourth of the year – a typical number for agricultural equipment, as machinery for seeding or harvesting is used sessional. As the pyrolysis unit is mobile, the plant can easily be transported to saw mills or to water treatment companies for saw dust or sewage sludge pyrolysis to increase the yearly operation hours. This increase of the operation hours could decrease the production costs for pyrolysis liquids by further 10 to 20 percent, leading to a price of less than 20 € per MWh. Adding cost of carriage from the mobile pyrolysis unit to a central energy conversion plant of approximately 4 €/MWh for a 100 km transport by truck, the overall costs are still less compared to fossil fuel [11].

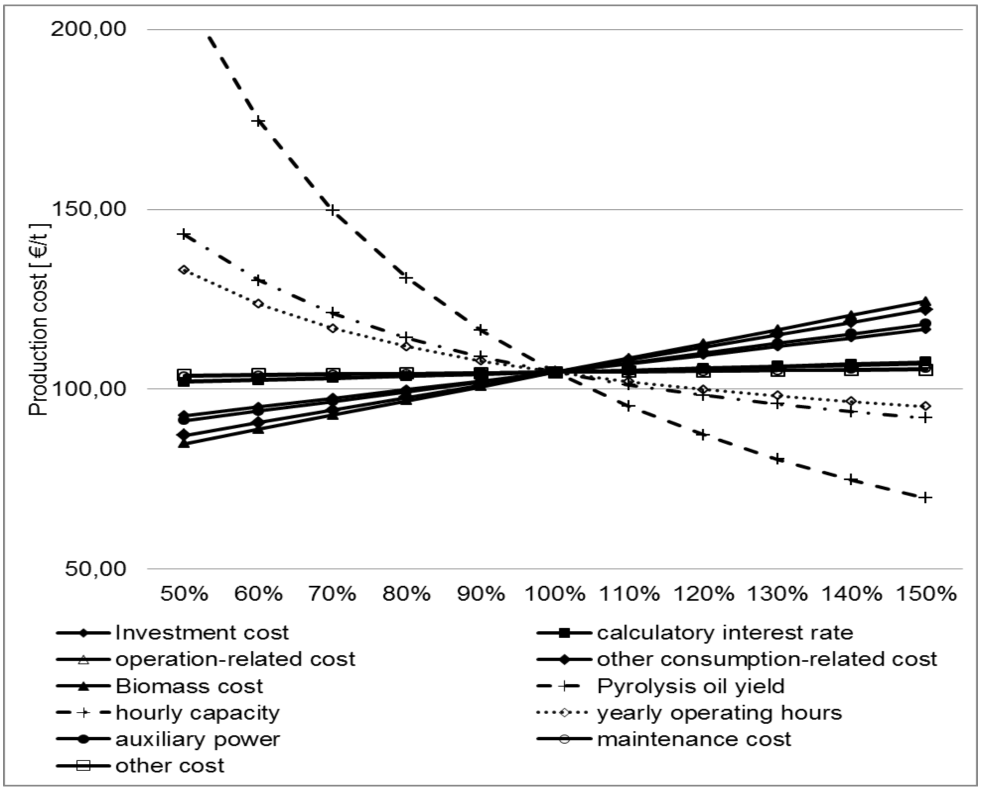


Figure 6. Sensitivity graph for on site pyrolysis [4].

6. SUMMARY

In the frame of the Fraunhofer Innovation cluster »Bioenergy« several bioenergy conversion technologies are investigated and evaluated. One main pillar of the cluster is the thermochemical treatment of straw using ablative fast pyrolysis (AFP). At Fraunhofer UMSICHT in Oberhausen, Germany, two of these AFP reactors in laboratory and pilot scale have been installed. Besides the technical feasibility, investigations in terms of the economy for mobile on site application have been carried out. The economic calculations have shown, that the major part ($4/5^{th}$) of the market price for straw originates from logistic costs. Avoiding these logistic costs is possible, by applying mobile on field pyrolysis. This route leads to the generation of pyrolysis liquids with a price of around 23 €/MWh which is highly competitive to fossil fuels like heating oil (80 to 90 €/MWh) or for heating gas (70 €/MWh). Sensitivity analysis were carried out, demonstrating that the highest influence on the costs is exerted by the yield of pyrolysis liquids per ton of feedstock. But as this yield is more or less determined by the pyrolysis temperature it can be considered as stable for a specified, optimum pyrolysis temperature of about 500 to 550 °C. The sensitivity analysis further gave evidence that the hourly capacity and the yearly operation hours are the main tools improving the economy of the mobile scenario. Again, the hourly capacity or throughput per hour is constant and specified by the size of the plant, defined by the customer. The yearly operation hours, contrariwise, could be easily expanded to the double or triple amount, as the yearly operation hours of the plant are assumed to be only 1120 h/a analogous to agricultural harvester working only sessional. Thus, by implementing further feedstock streams as saw dust, sewage sludge or hay, the economy of the mobile pyrolysis process could be improved further by additional 10 to 20 % leading to costs for the generation of the pyrolysis liquid of about 20 €/MWh. These costs of 20 €/MWh do not include transportation costs from the mobile pyrolysis plant to the end user. Assuming transport costs of 4.3 €/MWh (19 €/t) for 100 km distance [11] the pyrolysis liquid produced by a mobile AFP unit is still far cheaper than crude oil (43 €/MWh).

7 REFERENCES

[1] A. Porteous, Energy from waste incineration a state of the art emissions review with an emphasis on public acceptability, Appl. Energy, 70, (2001) 157.

[2] T. Malkow, Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal, Waste Manage., 24, (2004) 53.

[3] Nova-Institut GmbH, Hürth, Germany, www.nova-institut.de/bio/data/images/10-11_flaechennutz-ung.jpg (accessed 09.07.2013).

[4] J. Westermeyer: Wirtschaftlichkeitsbetrachtung

einer mobile Pyrolyseeinheit, Master thesis, Ruhr-University Bochum, 2013.

[5] Lédé, J., Panagopoulos, J., Li, H.Z. and Villermaux, J., Fast Pyrolysis of Wood: direct measurement and study of ablation rate, FUEL. 1985, **64**, p 1514–1520.

[6] Peacocke, G.V.C.; Bridgwater, A.V.; Ablative plate pyrolysis of biomass for liquids, Biomass, Bioenerg., 1994, 7, 147-54.

[7] Bech, N.; Jensen, P.A.; Dam-Johansen, K., Ablative flash pyrolysis of straw and wood: Bench-scale results, Proceedings of fifteenth European biomass conference and exhibition, ETA Florence, Berlin, Germany (2007), pp. 1276–1284.

[8] N.Ibrahim, Peter A. Jensen, K. Dam-Johansen, Roshafima.R. Ali, and Rafiziana.M. Kasmani, World Academy of Science, Engineering and Technology 70 2012, p 495 – 501.

[9] VDI Guideline 6025: Economy calculation systems for capital goods and plants, Verein deutscher Ingenieure, Düsseldorf, Germany, 1996.

[10] C.A.R.M.E.N. e.V, CENTRALES AGRAR-ROHSTOFF- MARKETING- UND ENERGIE-NETZWERK, http://www.carmen-ev.de/infothek/preisindizes/hackschnitzel/graphiken, (accessed, 05.07.2013).

[11] L. Leible, S. Kälber, G. Kappler, S. Lange, E. Nieke, P. Proplesch, D. Wintzer und B. Fürniß, Kraftstoff, Strom und Wärme aus Stroh und Waldrestholz–Eine systemanalytische Untersuchung, Wissenschaftliche Berichte FZKA 7170, 2007.

8 ACKNOWLEDGEMENT

The Fraunhofer Innovation-cluster »Bioenergy« is partly funded by the Ministry for Innovation, Science and Research of the German state of North Rhine-Westphalia (MIWF) with funds from the European Fund for Regional Development (EFRE) and by Fraunhofer Gesellschaft.

Ministerium für Innovation, Wissenschaft und Forschung des Landes Nordrhein-Westfalen

EFRE ...eine Chance durch Europa!

AVAILABILITY AND CHARACTERISTICS OF DIFFERENT WASTE SUBSTRATES FOR BIOGAS QUALITY AND POTENTIAL IN THE BALTIC SEA REGION (FIRST RESULTS OF THE PROJECT REMOWE-REGIONAL MOBILIZING OF SUSTAINABLE WASTE-TO-ENERGY PRODUCTION)

Silvia Drescher-Hartung, Ostfalia University of Applied Sciences, Salzdahlumer Strasse 46-48, 38302 Wolfenbüttel, Germany, s.drescher@ostfalia.de
Olga Anne, Klaipeda University, H.Manto, 84, LT-92294 Klaipeda, Lithuania, olga.anne@ku.lt
Thorsten Ahrens, Ostfalia University of Applied Sciences, th.ahrens@ostfalia.de

ABSTRACT: The overall objective of the REMOWE project is to contribute to sustainable and holistic development in the Baltic Sea Region through reduction of carbon dioxide emission by creating a balance between energy consumption and reasonable use of renewable energy sources. Project REMOWE had a strong focus on determination of energy resources from waste and furthermore mobilizing actions to promote sustainable implementation of energy efficient technology in the Baltic Sea region within the waste-to-energy area. Within the project REMOWE the Ostfalia University of Applied Sciences from Wolfenbüttel, Germany (BUA) is focused on data gathering and evaluation of organic waste, its composition and defining the biogas potential for different waste substrates. The waste streams that are considered were generated in the Baltic Sea Region of Poland, Estonia, Lithuania, Finland and Sweden and results from Lithuanian batch and continuous anaerobic digestion tests are presented in this paper. Project REMOWE has been the basis for a successful extension project application; acronym for the extension project is ABOWE. Grounded on the data ascertained in REMOWE suitable substrates were chosen and also suitable locations for the implementation of biogas plants were investigated.

WASTE, BIOGAS, IMPLEMENTATION

1 INTRODUCTION - PURPOSE OF THE WORK

According to the Directive 2009/28/EC (Renewable Energy Directive) the EU established targets which have to be reached by 2020. Thus until 2020 the overall share of the renewable energy in the EU has to be 20 % of the European energy demand. [1] Therefore anaerobic digestion is one possibility to achieve this objective. The REMOWE project presents the results of assessment of the current status of waste-to-energy utilization in five selected regions. It was partly financed by the European Union within the Baltic Sea Region Programme 2007-2013. [2]
The project partnership consists of the Mälardalen University, with the School of Sustainable Development of Society and Technology coordinating the project, and The County Administrative Board of Västmanland in Sweden, Savonia University of Applied Sciences, Centre for Economic Development, Transport and the Environment for North Savo, and University of Eastern Finland (UEF) in Finland, Marshal Office of Lower Silesia in Poland, Ostfalia University of Applied Sciences, Fachhochschule Braunschweig/Wolfenbüttel in Germany, Klaipeda University in Lithuania, and Estonian Regional and Local Development Agency (ERKAS) in Estonia. [4]

The five regions to be evaluated in this project were:

- Estonia – the whole country
- Lower Silesia – one of the 16 regions of Poland
- Western Lithuania – 4 counties of Lithuania
- North Savo region – a province in Eastern Finland
- The county of Västmanland – one of the 21 counties of Sweden [2]

National documents and strategies for the development of waste management and renewable energy law have been developed in each of these countries. Also most of the regions of the REMOWE project have own strategic documents such as waste management plans and energy strategies and furthermore strategies for energy recovery from waste, including renewable energy.

Anyway the development of waste management and energy recovery from waste is insufficient in all regions except for the County of Västmanland. [2]
The overall objective of the REMOWE project is to contribute to sustainable and holistic development in the Baltic Sea Region through reduction of carbon dioxide emission by creating a balance between energy consumption and reasonable use of renewable energy sources. Project REMOWE has been concentrated on energy resources from waste and mobilizing actions to promote sustainable implementation of energy efficient technology in the Baltic Sea region within the waste-to-energy area.

Within the project REMOWE the Ostfalia University of Applied Sciences from Wolfenbüttel, Germany (BUA) has been focused on data gathering and evaluation of organic waste, its composition and defining the biogas potential for different waste substrates. The waste streams that are considered generate in Baltic Sea Region of Poland, Estonia, Lithuania, Finland and Sweden.

The long-term goals to be achieved as a result of project implementation are:

- Increase of biogas generation and recovery of biodegradable wastes;
- Increase of requirements of local populations regarding products and services established with the use of waste derived energy;
- Increase of possibilities of appropriate technologies development;
- Increase of fossil energy sources substitution by energy from renewable sources;
- Decrease of energy use;
- Diminution of fossil fuel uses;
- Development of investments;

The aim of the mentioned part of the project which was adapted by several project partners was to investigate the current status in the whole chain of waste-to-energy utilization in each partner region.

Data have been collected concerning:

- Waste generation in farming, cities, industry;
- Energy use and infrastructure;
- Organic wastes composition and properties;
- Waste contamination by heavy metals;
- Waste calorimetric values;
- Biogas potential of different waste substrates;
- Existing systems and technology used for sorting, utilization and use of residues for/in waste-to-energy systems including economic profitability and system performance. [4]

The overall conclusion concerning digestion of waste and residue utilization includes contemplation about the total yearly amount that is produced, the suitability as fertilizer, a residual gas potential and general issues of the substrate-to-digestate process. The first comparative analysis of different substrates applicability for energy production from various Baltic Sea Region countries has been made; therefore unsorted municipal waste, biodegradable waste, and mixtures of industrial-agricultural substrates have been examined in continuous lab-scale fermenters under anaerobic conditions.
From March 2010 until September 2011 BUA analyzed different waste samples from the above mentioned regions with a special focus on determination of biogas potential and usability for anaerobic digestion of the substrates.

The substrates were visually classified and the amount of dry matter and organic dry matter was determined as a pre-test for decision about necessary pretreatments before further analytics. After these pre-tests, batch fermentation tests have been performed to determine the maximum biogas potential, and additionally continuous tests were operated to gather information about the long-term fermentation behavior of individual substrates and also of substrate mixtures. [3]

2 SUBSTRATES AND LABORATORY TESTS

2.1 Available and analyzed substrates

With reference to the actual legal situation as mentioned above biowaste and also organic fractions of municipal residual waste are possible substrates for anaerobic digestion. Moreover various organic materials (by-products in industrial or agricultural processes) and non-edible biomasses that do not comply with strict international or national food and forage regulations are possible substrates. [5]

Analysed waste types were:

- Municipal waste, crushed to 30mm and manually separated from glass, stones and metal (Kuopio, Finland),
- Separately collected biowaste (Västeras, Sweden),
- Mixture (kitchen and canteen waste, grease trap waste, edible fat, brewers' grains) (Estonia),
- Mixture (cow manure, screenings from sewage plant, palm oil, waste from spirit distillation, dried sewage sludge) (Lithuania),
- Dumped waste (Taurage, Lithuania),
- Edible fat (Estonia),
- Brewers' grains (Estonia). [5]

2.2 Materials and methods

For the determination of biogas potential of different materials two steps are necessary. By batch tests the maximum biogas potential will be determined, whereas by continuous tests the long-term fermentation behavior of the substrates were identified.

Batch tests will be performed in 5L-Erlenmeyerflasks under mesophilic conditions for 35 days under 40°C (see figure 1). During this time the produced gas will be collected in gas bags and the methane amount and content measured .

Figure 1: batch tests in heating cabinet [3]

As a second step continuous tests were performed in 15 L reactors, which are heatable and equipped with a stirring device. The continuous tests were operated at a temperature of 40-42 °C for at least three months.

Samples were taken from the reactors and the following analyses were done daily or weekly:

- determination of VOA/TAC value buffer capacity,
- pH-value,
- conductivity,
- amount of produced biogas,
- comparison of produced biogas,
- ammonium, phosphate, nitrogen concentration,
- dry matter and organic dry matter (DM/oDM),
- organic acids concentration. [5]

Following figure 2 shows the test systems for continuous experiments:

1. Stirring device
2. Water seal
3. Double walled heating coat
4. One of four water supply ports
5. Sampling connection
6. Gasbag with devices

Figure 2: continuous labfermenter [3]

2.3 Results of laboratory tests

As mentioned above using waste as substrate for anaerobic digestion demands special preparation and not every kind of waste, although it has organic contents, is suitable for this kind of energy production.

Therefore it has to be considered that if working with waste the different needs concerning pre-sorting, sanitation or disposal of the digestate might be necessary. [3]

The main results of the batch tests, which are the maximum substrate-specific methane potentials, are shown in table 1.

Table 1: Methane potential of the substrates (batch tests) [5, adapted]

region/city	**Nm3(CH4)/ Mg(fresh mass)**	**Nm3(CH4)/ Mg(oDM)**
Kuopio household waste average	69.4	286.7
Västeras, biowaste	146.8	564.0
Estonian Mix	259.8	621.4
Lithuanian Mix	85.2	462.2
Taurage, dump waste	18.7	126.6
edible fat, Estonia	745.0	745.6
brewers' grains , Estonia	93.8	446.3

One remarkable result of the analyzed substrates is that especially dumped waste (more than 6 months) is not anymore suitable for anaerobic digestion, but fresh household waste has a proper methane potential.

Animal faeces as cow manure are suitable co-substrates, but not for sole use. The use of biodegradable kitchenwaste and canteen waste produces acceptable methane outputs and the digestate is useful as fertilizer, but it has to be considered that the composition differs throughout the seasons.

Municipal household waste contains many disturbing materials, which leads to a high effort in pretreatment. Nevertheless the organic content really fits for anaerobic digestion.

Also industrial organic wastes (e.g. from distillery or food industry) are suitable especially as co-substrates. [3] One basic requirement when using residual organic wastes as substrates for anaerobic digestion is an adjusted pre-sorting of the material. It is absolutely necessary because residual waste contains many contaminants. These are for example plastics, metals, fibers, stones or wood pieces.

When using substrates with animal origins also a sanitation step is necessary. In the laboratory tests the substrates which had to be sanitized were heated either at 70°C for an hour or at 55°C for 10 hours at minimum. Sanitation can also cause an influence on the methane production, which increased at the same time. An example of the influence on the methane production is shown in figure 3.

A comparison of continuous tests is more difficult, because different waste mixtures were used, which had different characteristics and peculiarities. [3]

To limit extend of this paper only results of the laboratory test with Lithuanian substrates are considered below.

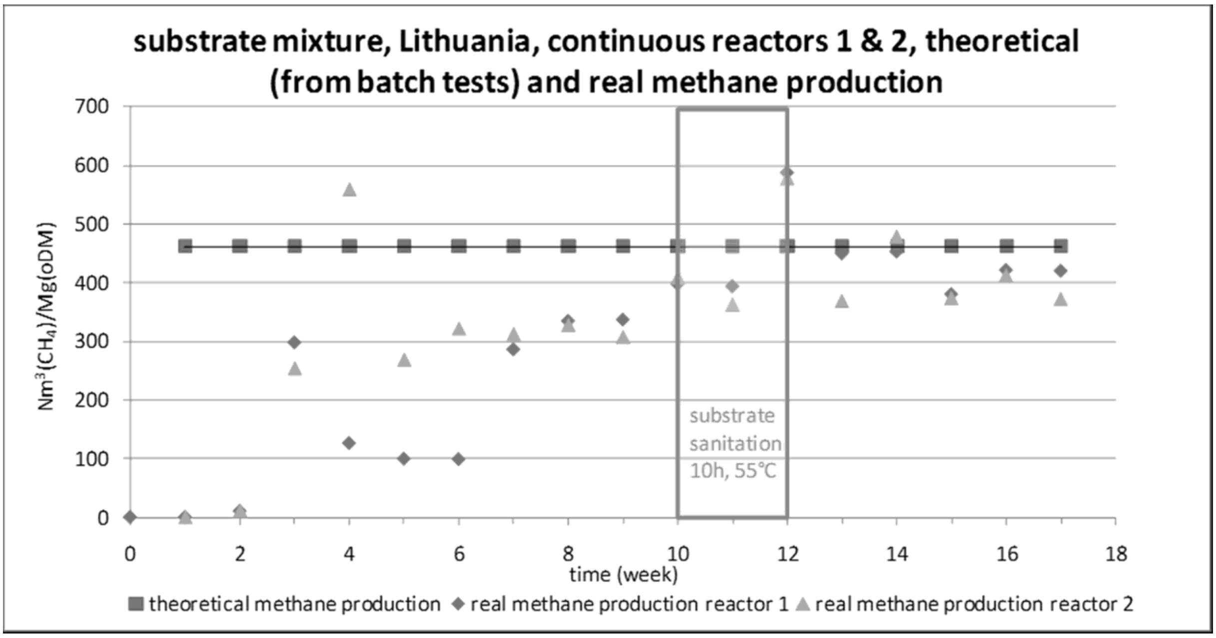


Figure 3: substrate mixture, Lithuania, continuous reactors 1 & 2, theoretical and real methane production [3]

Additionally analyses of heavy metals were done by the Klaipeda University of Applied Sciences in Lithuania.

Table 2 shows the results of heavy metal analysis of the substrate mixture which was used for the continuous tests. The Directive 86/278/EEC sets limit values for concentrations of heavy metals in the soils, in sludge and for the maximum annual quantities of heavy metals which may be introduced into the soil by the use of sewage sludge (see in table 2). Comparing to these limits the limit values set by the Regulation for biowaste in Germany (Bioabfallverordnung – BioabfV) are also shown in table 2.

Table 2: substrate mixture, Lithuania, continuous reactor 1, heavy metal analysis (mg/kg DM) and limits [10, adapted]

	limit (mg/kg DM) , 86/278/EEC [8] (mg/kg DM)	limit mg/kg DM , (Biowaste Ordinance, (Bioabfallverordnung - BioAbfV), §4) [9] (mg/kg DM)	reactor 1 (mg/kg DM)
chrome (Cr)	n.a. at the moment	70/100	4.75
copper (Cu)	1000-1750	70/100	83.48
nickel (Ni)	300-400	35/50	3.94
zinc (Zn)	2500-4000	300/400	292.83
cadmium (Cd)	20-40	1/1.5	0.38
lead (Pb)	750-1200	100/150	6.15
mercury (Hg)	16-25	0.7/1	0.18

Considering the suitability of the digestate residue as fertilizer, all analyzed substrates show low heavy metal concentrations under international limits. [10]

3 EXTENSION OF REMOWE – PROJECT ABOWE

3.1 Construction and operation of a pilot biogas plant

One workpackage task of ABOWE consists of the operation of a pilot biogas plant, which was manufactured in Germany under supervision of Ostfalia University of Applied Sciences, in the chosen location with a selection of substrates being tested in REMOWE. This pilot plant consists of a transportable horizontal plug flow digester with process automation, gas measurement, horizontal stirrer units and a volume of overall approximately 600 liters. This pilot plant is a downscale of existing biogas technology and outfitted with all necessary laboratory equipment for measurement of biogas and substrate composition (see figure 4 and 5).

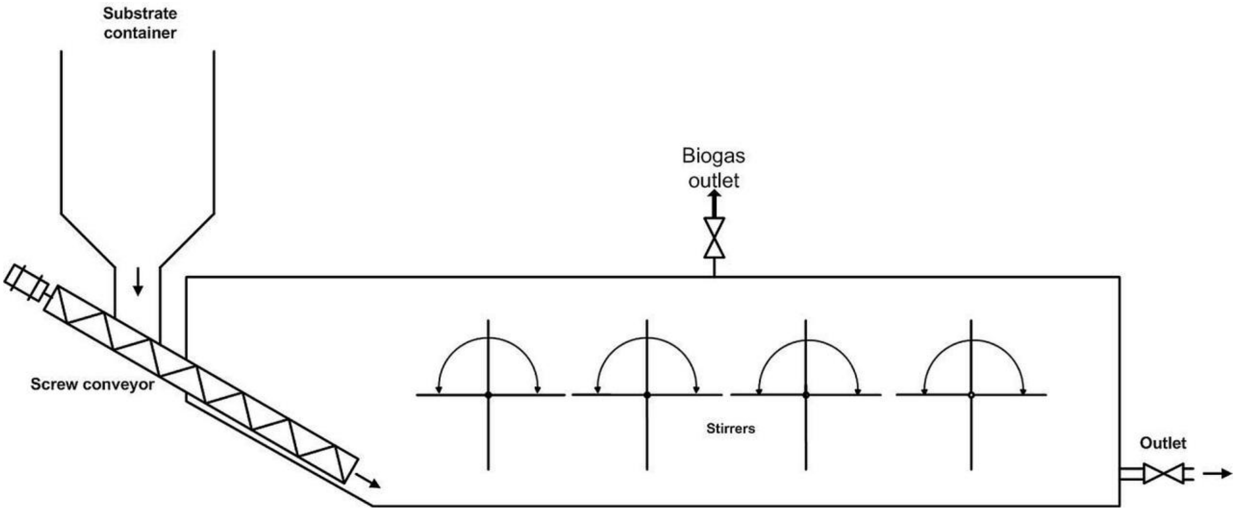


Figure 4: schematic drawing Pilot dry digestion biogas plant [7]

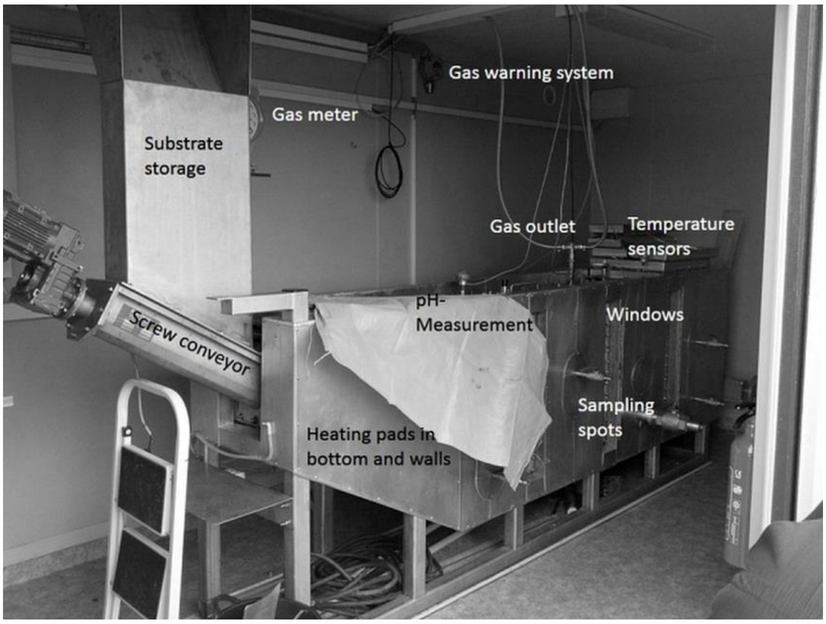


Figure 5: pilot biogas plant (inside view of the 20 ft-container)

Target goal is to perform full practical process simulation from advanced laboratory scale to pilot scale under consideration of regional implementation and knowledge generation. Anyhow it is important to notice, this that pilot biogas plant is designed to be an experimental training plant and not considered for commercial production of biogas in small scale.

The outcomes of the operation of the pilot plant in each partner region shall become the basis for a manual for regional decision taking of implementation of full scale dry digestion applications.

At first location the pilot plant has been installed in Lithuania in the region of Šilutė and will be in operation there till end of September 2013 with waste streams from local suppliers. After this first period the plant will be transported and operated in Estonia; last operation region will be in Sweden. The aim is

- to train potential future biogas plant operators,
- to use dry digestion applications for waste-to-energy concepts,
- to face the challenges of on-site regional conditions,
- to develop solutions to existing challenges in the addressed region. [6]

3.2 Holistic view – economic, political and legal

Objective of ABOWE is the transfer of knowledge. Besides to technical data also economic data will be considered and are important for the implementation of biogas plants. Therefore a widespread consideration is necessary, which includes also the political and legal situation in the regarding region.

All determined data and given conditions are the foundations for potential investors to decide on investments. Therefore detailed information is given by the project processors. But not only will the potential investors be informed but also the citizens because they have to accept the new technology. Therefore intensive information sessions are intended to inform stakeholders and investors.

Here the approaches differ from each other in the countries where the testing regions will be located. In the case of Lithuania potential investors and waste suppliers shall be informed about the technology and the possibilities of the alternative generation of energy by the use of waste. The pilot plant is located on a small farm and serves as a training plant for learning about biogas technology. The person who runs the pilot biogas plant will afterwards be able to operate the plant and to train more people in biogas technology.

In case of Estonia the pilot biogas plant will be located at a larger farm, therefore the project deals with farm scale scenarios, whereas it is full-scale implementation scenario in the case of Sweden.

That means in case of Estonia waste from the region will be used for operating the pilot biogas plant. Thereby it is proposed to get to know the technology, to determine suitable waste streams and possibilities for covering a part of the energy demand by biogas.

Contrary to the first two regions biogas technology in Sweden is well founded. Here the approach is another one. The pilot biogas plant is used to improve the existing technology especially for the use with municipal household waste, because it is adapted for the use as a dry digestion plant.

As a first result of the project work two scenarios for the operation of the pilot biogas plant and consequential considerations (economic, financial, socio-economic, political and legal implementation) were developed for the region of Šilutė in Lithuania. In the first scenario the digestion of cattle manure and waste from bioethanol distillery will be considered, in the second scenario cattle manure with waste from distillery and food wastes from different resources, e.g. schools, canteens and restaurants. Scopes of these scenarios are to determine the capability of existing waste streams and the amount of biogas which could be produced by using them for anaerobic digestion. Thereby the determination of the possible covering of the energy demand (electricity and heat) is a basic aim of this project.

Further scenarios will be developed for the partner regions. Thus a widespread data and knowledge base will be formed for the implementation of a promising investment in a technology for alternative energy sources.

4 REFERENCES

[1] European Commission: Proposal for a Directive of the European Parliament and of the Council. http://ec.europa.eu/energy/renewables/biofuels/doc/biofuels/com_2012_0595_en.pdf (accessed June 2013)

[2] den Boer, E., den Boer, J., Szpadt, R.: Waste-to-Energy in the Baltic Sea Regions; Report no: O3.2.2, Project REMOWE, November 2011, ISBN 978-83-930721-2-5

[3] Behrendt, A., Vasilic, D., Ahrens, T.: Report on substrate pretreatment, quality and biogas potential of different waste substrates and suitable substrate mixtures for each individual region, Report no: O3.2.3.1, Project REMOWE, www.remowe.eu, August 2011

[4] Behrendt, A., Vasilic, D., Ahrens, T.: Report on biogas utilization strategies, Report no: O3.2.3.3, Project REMOWE, www.remowe.eu, March 2012

[5]Behrendt, A., Drescher-Hartung, S., Ahrens, T.: Optimization of biogas processes: European experiences, in: Dahlquist, E.: Technologies for Converting Biomass to Useful Energy, Chapter 10, CRC Press, Taylor&Francis Group, 2013

[6] abowe, Newsletter 01/2013, ABOWE in Lithuania, www.abowe.eu

[7] Freidank, T.: Inbetriebnahme einer Versuchsbiogasanlage im Pilotmaßstab und Optimierung des Prozesses unter Einsatz von verschiedenen Hilfsstoffen. bachelor thesis, Ostfalia University of Applied Sciences, Wolfenbüttel, August 2010 (unpublished)

[8] European Commission. (2010, 02 22). Summaries of EU legislation. Retrieved 09 2011, from http://europa.eu/legislation_summaries/agriculture/environment/l28088_en.htm (accessed June 2013)

[9] Bundesministerium der Justiz: Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Bioabfallverordnung – BioAbfV) v. 21.09.1998, http://www.gesetze-im-internet.de/bundesrecht/bioabfv/gesamt.pdf (accessed June 2013)

[10] Behrendt, A., Vasilic, D., Ahrens, T.: Strategies on concerning digestion residue utilization, Report no: O.3.2.3.2, Project REMOWE, www.remowe.eu, September

CAN BIOAVAILABILITY OF TRACE NUTRIENTS BE MEASURED IN AN AD PROCESS?

Markus Ortner, Bioenergy 2020+ competence centre; Konrad Lorenz Str. 20, A-3430 Tulln – Austria
tel +43-2272-66280-536 email: markus.ortner@bioenergy2020.eu

Markus Ortner, Bioenergy 2020+, Konrad Lorenz Str. 20, A-3430 Tulln, tel +43-2272-66280-536, email: markus.ortner@bioenergy2020.eu
Lydia Rachbauer, Bioenergy 2020+, Konrad Lorenz Str. 20, A-3430 Tulln, tel +43-2272-66280-535, email: lydia.rachbauer@bioenergy2020.eu
Walter Somitsch, Ingenieurbüro Dr. Walter Somitsch, Wiedner Hauptstrasse 90/2/19, A-1050 Vienna, Austria; tel +43-664-4137710; email: office@somitsch.at
Werner Fuchs, BOKU University Vienna/ IFA Tulln, Konrad Lorenz-Str. 20, A-3430 Tulln, tel +43-2272-66280-553, email: werner.fuchs@boku.ac.at

Abstract: The rising interest in biogas production leads to increasing research on optimization strategies of the anaerobic digestion process. One of the strategies to improve the process stability and the biogas production rate is to ensure the optimum supply of mineral nutrients needed for growth and enzyme activity in the digestion process, both in quantity and composition. Supplementation of those micro nutrients is required, which are not sufficiently provided by the input material. A wide spectrum of commercial products is available, more or less addressing specific needs for trace elements. The addition of trace elements always implies the risk of overdosing of heavy metals which can cause toxic effects on microbial growth and metabolism as well as environmental pollution. Therefore substantial knowledge on dosage effects with respect to substrate composition and bioavailability of the considered minerals is necessary. In the literature many authors describing the need supplementation of micro nutrients in anaerobic digestion of both agricultural substrates and the organic fraction of municipal waste but do not consider the chemical speciation of the element, which causes different degrees of bioavailability. Until today it is a common practice to draw conclusions from analysis of total micronutrient content in biogas samples.

Within this work the aim was to test the applicability of a sequential extraction scheme established for soil and sediment samples with high inorganic compound structure on biogas slurries with a high amount of organic compounds. For that reason the modified Tessier scheme of sequential fractionation were adapted. This analytical procedure yields in four different fractions, an exchangeable fraction, a carbonate fraction, a fraction of organic matter and sulfides, and a residual fraction.

Instead of a drying step as sample preparation we generated a fifth fraction consisting of the centrifugate of the native sample. Both our adapted method (SE-B) and the original modified Tessier scheme (SE-A) were compared to determine the analytical impact of the pretreatment caused by drying and milling.

Besides the evaluation of reproducibility of the analytical methods attention was given to the interpretability of the obtained results based on chemical characteristics of the samples and on thermodynamic considerations.
The topic of this research is highly relevant to the scientific community and to the industry as well, especially due to the fact that the introduced approach is able to reflect the bioavailable amount of micronutrients in an AD-digester in a more exact and proper way than the usually applied methods. Thus it might be possible to produce tailor-made supplement solutions by avoiding overdosing and excessive material costs. This approach has a high innovative character, because it allows deeper insights in the interrelation of micronutrients in a complex medium such as AD slurry. Furthermore it could be shown which of the sample preparation conditions has the most significant impact on the bonding state of a single element which is direct related to the bioavailability of the considered micro element.

Both applied methods were proven for their successful applicability of the sequential extraction technique on micronutrients out of AD slurries. Both procedures fulfilled the basic requirements of reproducibility, time-saving analytical approach and economic feasibility for three different AD slurries (crops, animal and mixed). Recovery rates of 90 to 110% were obtained for the most important trace elements (Fe, Co, Cu, Mn, Mo, Ni and Zn). Applying the original Tessier method (SE-A) fractionation data indicated that up to 98 % of these essential micronutrients can be present in an insoluble and thus in a non-bioavailable form. Applying the modified method (SE-B) a significant higher concentration of elements in the bioavailable forms could be determined.

Within this work, an analytical technique for sequential extraction of micronutrients in AD systems was successfully developed. The applicability of existing protocols established for soil and sediment samples was successfully demonstrated for AD-slurries. The main critical impact factors (such as thermal pretreatment, milling, presence of sulfides, quality and timing of sampling) on the fractionation pattern were identified and discussed. The adapted method

(SE-B) was proven to meet the specific characteristics of different liquid/pastes like biogas slurries and allows a more exact insight to trace element distribution in AD systems compared to the widely used method of total amount measurement. Theoretical expectations did correlate with the practical findings of this work.

Purpose of the work: The rising interest in biogas production leads to increasing research on optimization strategies of the anaerobic digestion process. One of the strategies to improve the process stability and the biogas production rate is to ensure the optimum supply of mineral nutrients needed for growth and enzyme activity in the digestion process, both in quantity and composition. Supplementation of those micro nutrients is required, which are not sufficiently provided by the input material. A wide spectrum of commercial products is available, more or less addressing specific needs for trace elements. The addition of trace elements always implies the risk of overdosing of heavy metals which can cause toxic effects on microbial growth and metabolism as well as environmental pollution. Therefore substantial knowledge on dosage effects with respect to substrate composition and bioavailability of the considered minerals is necessary. In the literature many authors describing the need supplementation of micro nutrients in anaerobic digestion of both agricultural substrates and the organic fraction of municipal waste but do not consider the chemical speciation of the element, which causes different degrees of bioavailability. Until today it is a common practice to draw conclusions from analysis of total micronutrient content in biogas samples.

Approach: Within this work the aim was to test the applicability of a sequential extraction scheme established for soil and sediment samples with high inorganic compound structure on biogas slurries with a high amount of organic compounds. For that reason the modified Tessier scheme of sequential fractionation were adapted. This analytical procedure yields in four different fractions, an exchangeable fraction, a carbonate fraction, a fraction of organic matter and sulfides, and a residual fraction.
Instead of a drying step as sample preparation we generated a fifth fraction consisting of the centrifugate of the native sample. Both our adapted method (SE-B) and the original modified Tessier scheme (SE-A) were compared to determine the analytical impact of the pretreatment caused by drying and milling.
Besides the evaluation of reproducibility of the analytical methods attention was given to the interpretability of the obtained results based on chemical characteristics of the samples and on thermodynamic considerations.

Scientific innovation and relevance: The topic of this research is highly relevant to the scientific community and to the industry as well, especially due to the fact that the introduced approach is able to reflect the bioavailable amount of micronutrients in an AD-digester in a more exact and proper way than the usually applied methods. Thus it might be possible to produce tailor-made supplement solutions by avoiding overdosing and excessive material costs. This approach has a high innovative character, because it allows deeper insights in the interrelation of micronutrients in a complex medium such as AD slurry. Furthermore it could be shown which of the sample preparation conditions has the most significant impact on the bonding state of a single element which is direct related to the bioavailability of the considered micro element.

Results: Both applied methods were proven for their successful applicability of the sequential extraction technique on micronutrients out of AD slurries. Both procedures fulfilled the basic requirements of reproducibility, time-saving analytical approach and economic feasibility for three different AD slurries (crops, animal and mixed). Recovery rates of 90 to 110% were obtained for the most important trace elements (Fe, Co, Cu, Mn, Mo, Ni and Zn). Applying the original Tessier method (SE-A) fractionation data indicated that up to 98 % of these essential micronutrients can be present in an insoluble and thus in a non-bioavailable form. Applying the modified method (SE-B) a significant higher concentration of elements in the bioavailable forms could be determined.

Conclusions: Within this work, an analytical technique for sequential extraction of micronutrients in AD systems was successfully developed. The applicability of existing protocols established for soil and sediment samples was successfully demonstrated for AD-slurries. The main critical impact factors (such as thermal pretreatment, milling, presence of sulfides, quality and timing of sampling) on the fractionation pattern were identified and discussed. The adapted method (SE-B) was proven to meet the specific characteristics of different liquid/pastes like biogas slurries and allows a more exact insight to trace element distribution in AD systems compared to the widely used method of total amount measurement. Theoretical expectations did correlate with the practical findings of this work.

HEAVY METAL CONTAMINATED SEWAGE SLUDGE CO-GASIFICATION OF WOODY BIOMASS

Marius Praspaliauskas

Laboratory of Heat-Equipment Research and Testing, Lithuanian Energy Institute, Breslaujos str. 3, LT-44403 Kaunas, Lithuania

Introduction

Due to development of plumbing and wastewater accumulation network in the country using EU support, the amount of formed sewage sludge will be on the increase in the future. Sewage sludge is an inevitable product of the wastewater cleaning process, which contains many harmful materials. The presence of harmful substances such as heavy metals, poorly biodegradable organic compounds, viruses, pharmaceuticals and hormones, may represent a complication in the disposal management strategies [1]. The landfill disposal has become much less acceptable in many countries because it requires a lot of space and the soil has to be sealed adequately to prevent the leaching of toxic compounds.

Biomass is abundant, renewable, and low cost. Forestry waste, one of the most important biomass sources, was considered as a suitable feedstock for gasification. Compared with sewage sludge, forestry waste contained high contents of volatile matter and fixed carbon, but low ash and moisture contents.

Currently, most of the volume of sewage sludge is deposited in landfills and storage sites, used in agriculture and energetic, respectively 40 % and 37 %, 11 % is combusted, 12 % of sewage sludge is used in areas such as forestry, energy crops, renewal of degraded areas and others [2]. In Lithuania, the biggest part of sewage sludge is accumulated in storage sites and only a quarter of the total amount of sludge is used for various purposes so there is a problem how to use the sewage sludge from storage sites effectively.

Sewage sludge reuse [3,4]**:**

- Combustion without energy release.
- Agriculture:
  - Fertilization of the food culture;
  - Reconstruction of the degraded areas;
  - Forestry;
  - Energetic plants;
  - Etc.
- Combustion:
  - Multiple-hearth furnace;
  - Fluidised bed;
  - Smelting and rotary furnaces;
  - Etc.
- Co-combustion:
  - With coal;
  - With other fuels (e.g. biomass);
  - With municipal solid wastes;
  - In other processes (e.g. cement production).
- Alternative processes (thermal):
  - Pyrolysis;
  - Gasification;
  - Hybrid methods.

Methods

Samples of sewage sludge were collected in polyethylene containers before the sludge was discarded on the plant dump at the wastewater treatment plant in Kaunas, Lithuania. In the laboratory, the samples were dried for 18 hours within a laboratory low temperature electrical furnace SNOL60/300 LFN at 105 ºC. The samples were then ground and homogenized with Retch SM 300 mill through a mesh of 150-mm pore size. After that, the sewage sludge samples were mixed with wood pellets in five proportions: 100 % sewage sludge, 100 % wood pellets, 30 % ss/70 % wp, 50 % ss/50 % wp, 70 % ss/30 % wp.

Heavy metals of sewage sludge (As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Zn) were determined using inductively coupled plasma optical emission spectrometer ICP-OES (Optima 8000). Prior to that the samples were mineralized with Multiwave 3000 mineraliser.

Thermogravimetric analysis (TGA 4000) was used to gasify the prepared fuel mixes. About 5 mg of sample was gasified under approximately 5 %, 10 %

and 17,5 % air flow at a heating rate of 20 ˚C /min from 30 ˚C temperature to 995 ˚C [5].

Ash content was determined using standardised method LST EN 14775:2010 to verify the efficiency of gasification.

Ultimate analysis was used to determine the CHNS- and O content with Flash 2000 analyser.

Calorific value determination was performed to determine the Highest Heating Value (HHV) of the samples' mixes.

Results

Moisture content of sewage sludge was 89,9 % and of wood pellets it was 58,4 %. The result of the study showed that the largest concentration of heavy metals in Kaunas city are: Fe>Mn>Zn>Cu>Cr>Ni>Pb. Cobalt, mercury and molybdenum concentrations in sewage sludge were the lowest and the arsenic cadmium and selenium levels were below the detection limit (**1 Table**). In accordance with the requirements of LAND 20-2001 Lithuanian standard, sewage sludge is assigned to category I-II.

1 Table. Heavy metal concentrations in sewage sludge.

Metals	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	**Mo**	**Ni**	**Se**	**Zn**
Conc., (mg/kg)	3.88<	0.09<	221.4	3.95	256.4	12600	54.84	954.7	0.46	0.35	60.13	2.22<	354.4

Analysis of the main fuel cells showed that with the decrease of sludge quantity in fuel nitrogen, sulphur, and oxygen decrease respectively but hydrogen and carbon increase (**Fig. 1**). It is important to notice that sewage sludge has relatively large amount of sulphur. **Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants maintains that the use of oil** containing more than 1 % of sulphur is prohibited. In this case, sewage sludge contains 1.24 % of sulphur.

High heating value of sewage sludge was 12433 J/g and of wood pellets it was 19000 J/g. Calorific value of fuel mixes were gradually decreasing when quantity of sludge increased: 30ss/70wp-mixed fuel calorific value was 16494 J/g, 50ss50wp J/g, 15110, 70ss/30wp-14920 J/g.

Ash content in sewage sludge can reach more than 50 % and from the energetic viewpoint it is not a good indicator of fuel [6]. The analysis showed that ash content in sewage sludge was 44,92 %. Mixing sewage sludge and wood pellets together, ash content in the fuel is decreased **Fig. 2**. (ash content in wood pellets is about 1 %).

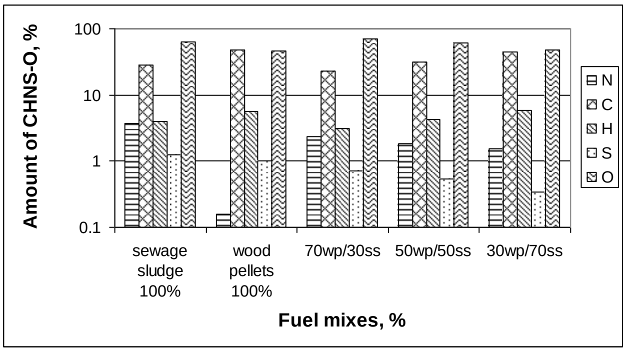


Fig. 1 C, H, N, S and O amount in fuel mixes.

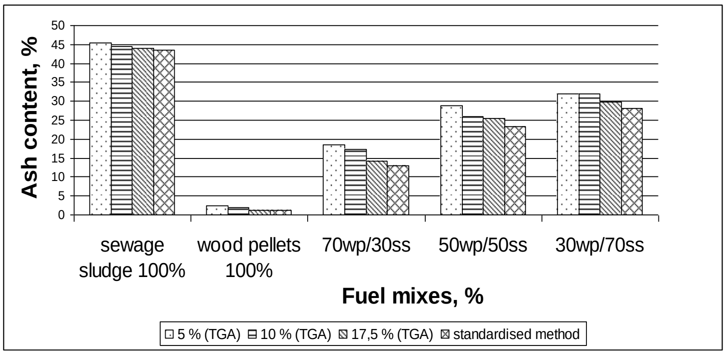


Fig. 2 Ash content in fuel mixes using standardised method and termogravimetric analyser.

Thermogravimetric analysis or thermal gravimetric analysis (TGA) is a method of thermal analysis when changes of physical and chemical properties of materials are measured as a function of increasing temperature (with constant heating rate), or as a function of time (with constant temperature and/or constant mass loss:

$$\frac{dm}{dt(T)} \qquad (1)$$

Determination of typical temperatures of reactions is easier and more accurate using differential curves compared with application of TGA curve. The peak of the DTG curve tip corresponds to the ultimate speed of mass decline, i.e. the real temperature of reaction. The presented graphs in figure 3 show that during the implementation of gasification of the fuel samples, three reactions peaks are characteristic. The first peak – at the very beginning of gasification from 30 °C to 110 °C, the second and the utmost – from 225 °C to 400 °C, and the third – between 700 °C and 800 °C.

During the implementation of gasification of the fuel samples and during the change of air supply to the furnace of TGA analyser, typical temperatures of reactions remain the same, yet the loss of different fuel mass occurs during reactions. During the first peak from 30 °C to 110 °C, the only loss is of H_2O. The biggest loss of mass, regardless of the air supply to the furnace, occurs during the second peak - from 225 °C to 400 °C. This could be due to lignocellulose which makes the biggest part of the wood [5]. According to the sources of literature [7], the biggest part of gasification products (the residual H_2O, CO, CO_2, H_2, CH_4 and C_mH_n) forms during this peak. The biggest mass loss of the wood biomass, followed by 30d/70b fuel mixture, 50d/50b, 70d/30b and finally sewage sludge, occurs during the second peak. During the third peak, when the temperature is between 700 °C and 800 °C, the changes of fuel mixtures mass change. During these reactions, sewage sludge, 70d/30b, 50d/50b, 30d/70b and wood biomass lose the most of mass.

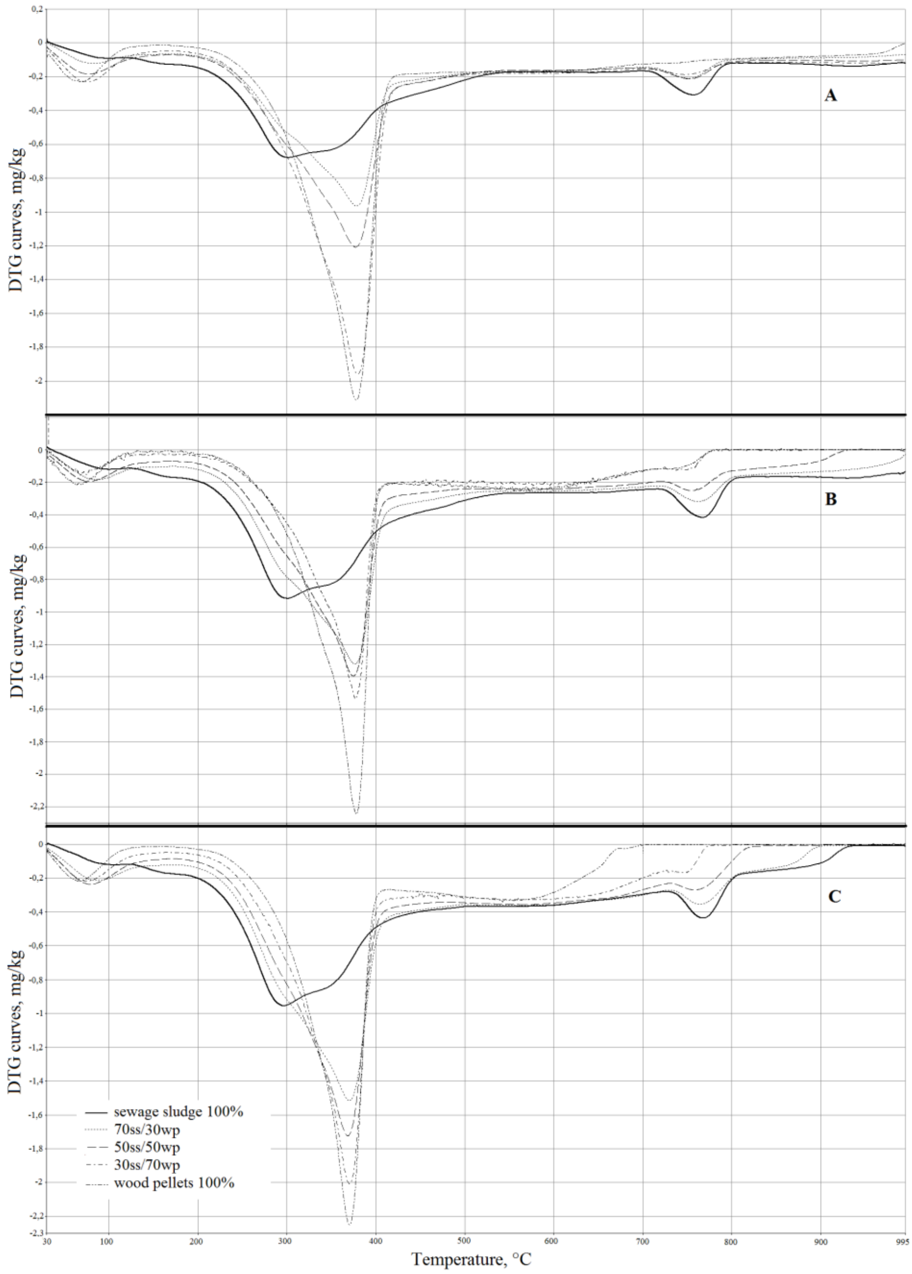


Fig. 3 DTG curves of fuel mixes (air supply A-5 %; B-10 %; C-17,5 %).

With the greater amount of wood biomass in fuel, the temperature of reaction decreases depending on the amount of the air supplied to the TGA furnace. When air supply is equal to 5 % (as presented in figure 3-A), gasification of wood biomass ends at 990 °C. When air supply is equal to 7 % (as presented in figure 3-B), gasification process for wood biomass and fuel mixture 30d/70b ends at the temperature of 776 °C and 778 °C respectively. Gasification process for the fuel mixture 50d/50b ends at the temperature of 926 °C. During gasification of fuel mixtures, when air supply to furnace is equal to 17,5 % (as presented in figure 3-C), the process ends for all fuel mixtures. Gasification process firstly ends for wood biomass when the temperature of 740 °C is reached. With the increase of sludge in fuel, the temperature of gasification reaction end increases respectively: 778 °C (30d/70b), 819 °C (50d/50b), 893 °C (30b/70d), 926 °C sludge.

The obtained results of fuel ash content were compared with the amount of ashes which had remained after TGA analysis. It was determined that during gasification of sludge and its mixtures with wood biomass, a relatively small unreacted part of fuel remains. With the increase of air supply to the furnace of TGA analyser, the difference between ash content, which was determined through standardized approach, and the results of TGA analyser decreases (refer to figure 2). Depending on the air supply to TGA furnace, the difference is very slight, from 1 % to 5 %.

Conclusions

1. According to Pb, Cd, Cr, Cu, Ni, Zn, and Hg concentrations, sewage sludge is assigned to the second category. Use of such sludge in agriculture is limited. In order to achieve more efficient use of sewage sludge, one of the alternatives is thermal degradation in gasification plants mixing with biomass. The optimal selection of such fuel mix would contribute to further solving of air pollution and synthetic gas quality issues.

2. After the completion of gasification of fuel mixtures, three peaks of fuel mass losses were determined. The first – at the very beginning of gasification process – from 30 °C to 110 °C, the second and the biggest – from 225 °C to 400 °C, and the third – between 700° C and 800 °C. It was determined that during gasification of sludge and its mixtures with wood biomass, the unreacted part of fuel remains relatively small, from 1 % to 5 %, depending on air supply to TGA furnace.

3. It was investigated that mixing sewage sludge with wood biomass, fuel quality deteriorates, in terms of energy, with the increasing quantity of sludge.

Literature

1. Ji, A.M., Zhang, S.T., Lu, X.B., Liu, Y. 2010. A new method for evaluating the sewage sludge pyrolysis kinetics. Waste. Manag 30:1225–1229.
2. Commission of European Communities. Council Directive 91/271/EEC of 21 March 1991. concerning urban waste-water treatment (amended by the 98/15/EC of 27 February 1998).
3. S. Wetle, R. Wilk. 2010. A review of methods for the thermal utilization of sewage sludge. The Polish perspective, Renewable Energy 35:1914–1919.
4. Fytili D, Zabaniotou A. 2008. Utilization of sewage sludge in EU application of old and new methods-a review. Renewable and Sustainable Energy Reviews 12:116–40.
5. Lixin Peng, Yongxiu Wang, Zhihong Lei, Gong Cheng. 2012. Co-gasification of wet sewage sludge and forestry waste in situ steam agent. Bioresource Technology 114: 698–702.
6. M. Otero, X. Gomez, A.I. Garcia, A. Moran. 2008. Non-isothermal thermogravimetric analysis of the combustion of two different carbonaceous materials, Journal of Thermal Analysis and Calorimetry 93:619–626.
7. M. Dogru. 2000. Fixed Bed Gasification of Biomass, PhD thesis, University of Newcastle, UK.
8. **Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants.**

INFLUENCE OF DIFFERENT PRETREATMENT METHODS ON DEGRADATION OF WHEAT STRAW

Timo Kikas, Marti Tutt, Jüri Olt
Institute of Technology, Estonian University of Life Sciences, 56 Kreutzwaldi Str, 51014, Tartu, Estonia
e-mail of corresponding author: timo.kikas@emu.ee
Oral presentation
Energy, biomass and biological residues

Key words: *wheat straw, glucose, dilute acid pretreatment, cellulose.*

Introduction

In recent years, many intensive studies have been made to develop efficient pretreatment technologies. The objective of efficient pretreatment is to break the lignin seal, increase hemicellulose disruption, decrease the crystallinity of cellulose and increase the biomass surface area so that structure of cellulose would be easily accessible by lignocellulosic enzymes for maximum recovery of sugars [1]. Among many different pretreatment processses, dilute acid and alkaline pretreatment have been reported as simple methods, but providing successful fractionation of lignocellulosic biomass [2]. Downside of the process is the need for high temperatures, over 180°C, which is limiting the cost effectiveness of converting lignocellulosic biomass to ethanol [3]. So there is a need for finding a simple and cost effective pretreatment method using mild operating conditions, while retaining good cellulose to sugars conversion rate.
The aim of this work was to compare the influence of different dilute acid and alkaline pretreatment methods of wheat straw for getting the best glucose yields under mild operating conditions. From different available feedstock wheat straw was chosen because wheat is the most widely grown cereal in Europe.

Materials and Methods

Dilute sulfuric acid, hydrochloric acid, nitric acid and potassium hydroxide solution were used for pretreatment. The size of samples was 100 g of dried and milled wheat straw to which 1000 mL of 1% acid or alkaline solution was added. All samples were heated for $t = 60$ minutes at a temperature $T = 130 \pm 3$ºC and a pressure of $p = 3$ bar. Pretreatment was followed by enzymatic hydrolysis with enzyme complex Accellerase 1500. Enzyme mixture was added to sample at a ratio of 0.3 mL per g of biomass. Hydrolysis lasted for $t = 24$ hours under constant stirring and at a temperature $T = 50$ºC. . After the hydrolysis process, glucose concentration in all samples was measured reflectometrically.

Results

Results indicate that the highest cellulose to glucose conversion rate of 310.0 g/kg of biomass was achieved by nitric acid pretreatment. The lowest glucose concentration of 221.3 g/kg was achieved by hydrochloric acid. In wheat straw samples pretreated with sulfuric acid, two different approaches were used. Solid part of half the samples was washed with water before adding enzymes and the rest of the samples were unwashed before enzymatic hydrolysis. As results indicated, sulfuric acid pretreated samples that were unwashed gave a glucose yield of 276.7 g/kg and samples that were washed before hydrolysis gave a glucose yield of 267.3 g/kg. Approximately 3.5% of cellulose is converted to sugars during acid pretreatment and is dissolved in the liquid part. Samples that were pretreated with dilute KOH solution and where the solid part was unwashed, glucose concentration was 221.7 g/kg which is different from KOH pretreated samples that were washed before hydrolysis, glucose concentration 267.5 g/kg. This can be explained by the different thickness of washed and unwashed alkaline pretreated samples, presence of dissolved lignin and short hydrolysis time. Unwashed samples were very thick and difficult to stir and dissolved lignin in solution is a known inhibitor to enzyme activity.

References

1. Kim, J. W., Kim, K. S., Lee, J. S., Park, S. M., Cho, H. Y., Park, J. C., Kim, J. S., 2011. Two–stage pretreatment of rice straw using aqueous ammonia and dilute acid, *Bioresource Technology*, 102, 8992-8999.
2. Sarkar, N., Ghosh, S. K., Bannerjee, S., Aikat, K., 2011. Bioethanol production from agricultural wastes: An overview, *Renewable Energy*, 37, 19-27.
3. Pedersen, M., Johansen, K. S., Meyer, A. S., 2011. Low temperature lignocellulose pretreatment: effects and interactions of pretreatment pH are critical for maximizing enzymatic monosaccharide yields from wheat straw, *Biotechnology for Biofuels*, 4:11.

PHENOLIC COMPOUNDS WITH ANTIRADICAL ACTIVITY FROM THE CORK BOILING WASTEWATER ANAEROBIC DIGESTION

I. P. Marques1, L. Gil1, F. La Cara2*
1 Laboratório Nacional de Energia e Geologia, I.P., Lisboa, Portugal
1 isabel.paula@lneg.pt, tel. +351 21 0924600 (corresponding author)*
2 Istituto di Biochimica delle Proteine, CNR, Via Pietro Castellino 111, 80131 Napoli, Italia
(+)39 0816132293, (+)39 0816132277, f.lacara@ibp.cnr.it

Abstract:

Purpose of the work. This work aims to develop a procedure that explores the different types of valorization that can be obtained by integrating a biological process, such as the anaerobic digestion, to promote the bioconversion of the industrial cork effluents (cork boiling wastewater, CBW).

Approach. This approach concerns to gain insight about the valuable molecules that are present in the CBW before anaerobic digestion process and in the digested flow. Anaerobic experiments were conducted under mesophilic conditions of temperature. Several important compounds of industrial interest were identify and quantified.

Scientific innovation and relevance. The main innovation of this work lies in the fact that the application of the anaerobic process has never been study in terms of the treatment and valorization of the industrial cork effluents. This is a very relevant work because the cork (outer bark of the cork-tree: Quercus suber L.) is a product of high environmental, economic and social importance in western Mediterranean region, being Portugal the world-leading producer and exporter.

Results. The achieved results indicate that the anaerobic digestion improves the CBW characteristics in terms of the industrial interest. An antiradical activity increase was registered due to the selective production of some phenolic compounds. Ten phenols (gallic acid, protocatechuic acid, caffeic acid, vanillic acid, syringic acid, ellagic acid, pcoumaric
acid, ferulic acid, o-coumaric acid and trans-cinnamic acid) were identified by HPLC analysis in the cork processing wastewaters and in the digested flow. Ellagic acid, present at concentration of 96.5 µg mL-1, and galic acid, at considerably lower amount (19.5 µg mL-1), are the major components of the CBW phenolic fraction. On the other hand, the concentration of phenols of benzoic acids family (gallic, protocatechuic, vanillic and syringic acids) and the o-coumaric acid have been improved during the anaerobic process.

Conclusions. The obtained data show that the anaerobic digestion can be regarded as a biological process that provides other profits than energetic and agricultural valorization of the industrial cork effluents. Industrial valuable molecules can be recovery under a multiple biochemical valorisation plan involving the anaerobic process. Some of these compounds, as the ellagic acid, are molecules that are important components of the human diet due to their potential antioxidant activity, their capacity to diminish oxidative stress-induced tissue damage resulted from chronic diseases, and their potentially utilization in cancer therapy.

PRODUCTION OF ENERGY AND CHEMICALS FROM BIOMASSES BY MICRO-ORGANISMS: "ABOWE" PILOT PROJECT

Ari Jääskeläinen, Savonia University of Applied Sciences, P.O.B. 6, FI-70201 Kuopio, Finland, p.+358 44 785 5571, ari.jaaskelainen@savonia.fi

Elias Hakalehto, Institute of Biomedicine, University of Eastern Finland, P.O.B. 1627, FI-70211 Kuopio, Finland, p. +358 500 574 289, elias.hakalehto@gmail.com
Anssi Suhonen, Savonia University of Applied Sciences, P.O.B. 6, FI-70201 Kuopio, Finland, p.+358 44 785 5558, anssi.suhonen@savonia.fi
Ari Jääskeläinen (contact info above)

Purpose of the work
The biorefinery concept developed by Dr. Elias Hakalehto/Finnoflag Oy is the basis for Work Package 3 of EU Baltic Sea Region Programme project ABOWE (Implementing Advanced Concepts for Biological Utilization of Waste, 12/2012-9/2014). This upstream bioprocess is based on accelerated bacterial metabolism in the 2,3-butanediol fermentation. This substance is a useful raw material for producing synthetic rubber, plastic monomers, anti-icing chemicals, textiles, cosmetics and many other commodities. Many kinds of biomasses, such as industrial wastes serve raw materials. Ethanol and hydrogen are valuable by-products of this fermentation. Semi-industrial implementation of novel production principles of this platform chemical are tested in three countries on different wastes. Downstream processing techniques are to be developed in cooperation with Ostfalia Technical University of Germany.

Approach
A semi-industrial mobile pilot plant and novel production principles will be designed, manufactured and tested with selected waste materials in Finland, Poland and Sweden. Ultimate aim is to provide Proof of technology and values for economical calculations, both needed in compiling Investment memos for Investor events. The desired outcome is implementer/investor driven continuation projects targeting full scale plant investments.

Scientific innovation and relevance
The biorefinery process' novelty is in improved productivity and versatile product repertoire. The production exploits results from basic research on the physiology and regulation of bacterial metabolism. This research has been accomplished in a laboratory scale, and in the field, by the PMEU enhanced cultivation unit (Portable Microbe Enrichment Unit) developed by Finnoflag Oy. When products can be produced faster, the minimum facility size reduces enabling lower investment. Moreover, downstream processing of the products is more affordable, when end product concentrations can be increased and the total duration of the process shortened. With the biorefinery pilot it can be experimented to produce valuable fuels and chemical products from various wastes.

Results
In case of food industry wastes, maximum productivities of 8-10 g/l/h of 2,3-butanediol have been achieved. The principles of the production concept on the basis of the cellular metabolism of *Klebsiella* sp. bacteria are discussed. The adjustment of the reactor hardware and its control system with the biological organisms and their enzymes as biocatalysts is producing desirable increase in the productivity. The same concept has been attempted also to the industrial acetone-butanol fermentation (ABE, acetone, butanol, ethanol) with hydrogen as by-product. In this process, for example, organic acid (butyric acid) is converted into alcohol (ethanol) by obligate anaerobic *Clostridium* sp. bacteria. If the conditions in the pilot plant are controlled in a correct way, this conversion reaction could become economically feasible producing alternative fuels for the car engines.

Conclusions
Due to the decreasing supply of cheap fossil fuels in global scale, increasing interest has been directed towards effective use of biomasses, including the organic wastes. The price of the utilized waste materials can be even negative, which improves the overall economies of these industrial applications. Tightening regulation upon discarding organic masses will boost future need for novel solutions. The ABOWE pilot plant project combines the understanding of the biological metabolism with clever reactor design in order to provide sustainable solutions for the industries. It utilizes biocatalysis for achieving these goals instead of extensive outside energy sources.

THE PROFITABILITY ANALYSIS FOR SUPPORT OF AGRICULTURAL ENTERPRISES IN SOUTH SAVO REGION

Soininen H.[1], Ranta-Korhonen T.[2]., Luste S.[3]
[1] Research Director, M.Sc. (Tech.), Mikkeli University of Applied Sciences, P.O. Box 181, 50101 Mikkeli, Finland. Tel. + 358 (0)400 869 952, e-mail: hanne.soininen@mamk.fi
[2] Project Assistant, M. Sc., Mikkeli University of Applied Sciences, P.O. Box 181, 50101 Mikkeli, Finland, e-mail: tuija.ranta-korhonen@mamk.fi
[3] Research Manager, Ph.D., Mikkeli University of Applied Sciences, P.O. Box 181, 50101 Mikkeli, Finland, e-mail: sami.luste@mamk.fi

ABSTRACT: Biogas production is very potential way to produce bioenergy in farms, which possess a sufficient quantity of cattle manure but also other biomasses. Utilization of biogas enables sustainable way to produce energy in farms increasing the economic competitiveness of agricultural enterprises. This is believed also to create new business opportunities in rural areas. The present study observes the centralized biogas production (< 20,000 t/a) to vehicle fuel, which is supposed to be the most ecological and economical way to utilize biogas and replace the fossil fuels. All the in-feed materials of the study are originated from the agricultural processes. At the present study, the model is used to analyze the profitability of the farm-scale vehicle fuel production via the two different content feed mixtures. The main aim was to study the affect of the main characteristics of the feed-materials related to the cost-effectiveness. The analysis indicates that, the income generated by vehicle fuel production from biogas will be sufficient to cover the plants' annual investment and operating costs. However without support and/or gate fees this was not possible with the in-feed materials and their relations studied.

Keywords: Biogas, Profitability, Vehicle fuel

1 INTRODUCTION

Anaerobic digestion process is a microbiological activity during which biomass is converted into two end-products: methane-rich biogas and nutrient-rich digestate. This process offers several advantages, including controlled stabilization of organic material with minimized environmental emissions, production of renewable energy (electricity, heat and/or vehicle fuel) and recycling of carbon and nutrients via the reuse of digestate.

Agriculture and farming are the main livelihood of the South-Savo region and the area is a good example of the present development of the rural areas in Finland, where farm sizes and the amount of by-products produced are growing with the similar decrease of the population and business opportunities. So, current farms are becoming more energy-intensive enterprises and there has been a growing interest in building biogas plants either on farm-scale or as co-operatives involving several farms, which may also increase the effective utilisation of agricultural waste streams in biogas production [1].

It is estimated, that at least 25% of all European bioenergy originated from farming and forestry, could be produced via biogas process in the future [2]. This estimation includes the biogas potential of manures with the implementation level of 40-70% (230 TWh/a) and plant biomass produced on 5% of the arable farmland (570 TWh/a; [3]). This would also have high contribution to the viability and improved economical potential of the rural areas such as to the decreased amount of greenhouse gas emissions from the agriculture, which with the fossil fuel based traffic are the most foremost sources of the greenhouse gas emissions in Finland. Biogas conversion to the vehicle fuel has supposed to have higher energy potential, when compared to the heat and/or electricity production from biogas. Moreover, when biogas is utilized as a vehicle fuel, replacing the fossil based fuels, the effects to the direct and indirect greenhouse gas emissions are the most effectual [4].

The most common base material for the digestion produced in the farms is cattle manure/ slurry. However, biological methane potential of cattle manure is relatively low (130-240 m^3 CH_4/tVS_{added}; [5, 6, 7, 8, 9, 10, 11]. To improve the economical feasibility of cattle manure based biogas plants, it is recommended that it is co-digested with other organic materials, such as plant biomass, swine- or chicken manure or other organic by-products from the agricultural- and/or industrial processes.

Co-digestion in-feed materials from the municipality (e.g., biowastes, sewage sludge) and industry (e.g., food processing industry, surplus foodstuff from restaurants and markets) need to be heat pre-treated before or after the digestion treatment [12], which may increase the investment and operational costs of the biogas process. However, the process suitable pre-treatments with synergy benefits may also improve the methane production and the profitability of the biogas production [1]. Co-digestion of several materials may also improve the profitability of the process via the possible gate-fee incomes, which are in important role at the moment to cover the expenses of the active biogas plants in Finland. It may also be beneficial for biogas plant to pay for the organic by-products and wastes with the high biological methane production potential and/or other synergy benefits for the process.

There are several factors, which are affecting to the profitability in the biogas production, e.g., availability and characteristics of material(s), type of the energy production plant (heat and/or heat & electricity and/or biofuel for vehicles), plant's heat and electricity consumption, investment costs, financial support, operational costs, energy prices, gate fees and case specific synergy benefits from the surroundings (e.g., Place to use the heat in the summer time, electric network ownership, logistic systems, value and commercial potential of digestate). Most important is to study the biogas production process as a case specific completeness. For example, for the view of the methane production it may be beneficial to co-digest available organic by-products from the industry which may also be beneficial for the buffer capacity of the process [1]. The high increase in prices of the mineral fertilizers makes it more attractive to use cattle manure based stabilized and nutrient rich digestate as a fertilizer. However, at this point the quality and content of digestate is highly important, especially in the field of the organic farming. Thus, utilizing of materials produced in farm(s), the digestate is considered suitable also for the higher quality standards of the fertilization.

The present biogas plant study was a partial task of partly EU-funded project "ESBIO – energy self-sufficient farm", which was implemented in the Mikkeli University of Applied Sciences in 2009-2012. One of the objectives was to evaluate the profitability of a farm scale biogas plant (material intake < 20,000 t/a). To support the profitability analysis and to make it more understandable, the calculation model was created. The project is partly founded by the EU (European Agricultural Found for Rural Development).

The main aim is to study the affect of the main characteristics of the feed-materials related to the cost-effectiveness (i.e., materials available from the farms and their co-digestion, level of support and gate fee payments).

2 MATERIALS AND METHODS

The section below sets out two calculation examples (Model 1, 2) outlining the effect of available in-feed materials on the profitability of a centralized farm-scale biogas plant producing biogas for the vehicle fuel. The cost calculations are based on the presumption that the plant's material flows chiefly from several farms and the plant is receiving material 19,500 t/a.

2.1 Plant type of the calculation models

The selected process of the present biogas plant consists of processing wet sludge under the mesophilic process conditions (~35 °C: Figure 1). The biogas plant is digesting materials formed only in the agriculture (i.e., animal manures and surplus fodder). Thus, hygienisation treatment (required for the by-products formed in industrial processes; [12]) is not needed. Plant is considered to be a joint plant digesting materials from the several farms and all materials and amounts are based on the situation in practise.

Model 1. studies co-digestion of cattle slurry (17,000 t/a) and green fodder (2,500 t/a), when Model 2. takes account of cattle slurry (14,000 t/a), chicken manure (2,500 t/a), horse manure (1,000 t/a) and green fodder (2,000 t/a).

Progress of the plant process: follows the subsequent list:

A) Feed material storage and processing
- Homogenisation
- Heating

B) Sludge digestion in the reactor
- 35 °C operational temperature, mechanical mixing and retention time of 21 days
- Post-digestion step of the reactor sludge

C) Post-digestion, storage, processing
- Biogas for the vehicle fuel
  - Upgrading of the methane content >95%
  - Pressuring of the methane
  - Supply for the vehicles
- Digested sludge as a renewable fertilizer
  - Storing and distribution to the fields

2.2 The in-feed materials used in the calculation models and the energy volume produced

It is presumed in the calculations that the biogas plants constituting the model examples will use a total of 19,500 tonnes of liquid cow manure (i.e., cattle slurry), dry chicken manure, horse manure and green fodder. All of these materials are produced in the farm(s), so no preliminary hygienisation treatments are needed.

Table I shows Calculation Model 1 indicating the material volumes processed per annum, their total solids (TS) and volatile solids (VS) contents, the estimated biological biogas production potential, and the methane volume produced from the materials consumed. The in-feed materials TS% values, VS%%TS values, and the biogas production capacity are based on the material flows verified by the results of a partly EU-funded research project titled "ESBIO - Energy Self-sufficient Farms in the South Savo Area". The results were obtained from laboratory tests and tests conducted on a pilot scale [13, 14, 15, 16].

Table 1: Calculation Model 1. Methane (CH_4) volume produced per annum (m^3/a)

Material	*Volume (t/a)*	*TS %*	*VS % % TS*	*Biogas potential ($m^3/kgVS$)*	*CH_4 (m^3/a)*
Cow slurry	*17,000*	*6*	*80*	*273,000*	*163,800*
Green fodder	*2,500*	*25*	*90*	*220,000*	*156,000*
Total	*19,500*	*8.0*	*85*	*475,500*	*315,000*

Table 2 shows Calculation Model 2 indicating the material volume processed per annum, the TS and VS content level used in the calculations, the estimated biogas production potential and the methane volume produced from the materials.

Table 2: Calculation Model 2. Methane (CH_4) volume produced per annum (m^3/a)

Material	Volume (t/a)	TS %	VS % % TS	Biogas potential ($m^3/kgVS$)	CH4 (m^3/a)
Cow slurry	14,000	6	80	218,400	131,040
Green fodder	2,000	25	90	230,000	138,000
Chicken manure	2,500	25	80	250,000	150,000
Horse manure	1,000	30	80	102,000	61,200
Total	19,500	10	81	800,000	480,000

The gross energy volume produced by calculation Model 1 is 3,150 MWh/a, yielding a vehicle fuel energy output of 3,100 MWh/a. The plant's own electricity energy consumption is 450 MWh/a and that of thermal energy 670 MWh/a, amounting to a total of 1,100 MWh/a.

The gross energy volume produced by calculation Model 2 is 4,800 MWh/a, yielding a vehicle fuel energy output of 4,700 MWh/a. The plant's own electricity energy consumption assessment is 680 MWh/a and that of thermal energy 1,000 MWh/a, amounting to a total of 1,700 MWh/a.

The analysis is based on an efficiency ratio of 0.7 in the in-house use of energy. The energy need of the vehicle fuel instrumentation (i.e., upgrading, pressuring and filling) is based both on the literature (0.17 – 0.22 €/Nm^3/CH_4; Ahonen et al., 2009) and the oral communications with the vehicle fuel producers (10-15 % of the net energy content).

2.3 Initial investment cost and operating cost values used in the calculation models

The biogas plant investment costs, including the planning and design work, buildings, process equipment and construction work, have been estimated to be €1.5 million, from which the proportion of the CHP unit is 200,000 €. The plant of the present study is not including the CHP –unit, but it is replaced with the instruments for the vehicle fuel production, which are screened to cost 300,000 – 400,000 €. The following Finnish companies, among others, have provided price information for the cost calculations: Metaenergia Oy, Metener Oy, NHK-Keskus Oy and Preseco Oy. In addition, initial information has been obtained from the report of a partly EU-funded research project that was implemented in 2006-2007 with the title ”Bioenergy for Agricultural Farms and Greenhouse Companies in South-Savo” [17] and from the results of a partly EU-funded research project that is still in progress with the title “ESBIO Energy Self-sufficient Farms” [18].

The present plant will produce solely vehicle fuel and the needed heat and electricity are bought from the general markets (25 €/MWh; 50 €/MWh; Based on the current energy prices). The annual operating costs have been estimated as follows, model 1: €163,000 and model 2: €214,000. The annual operating costs consist of the material flow transports, purchased services, personnel and machine work costs, the plant’s consumption of electrical and thermal energy, chemicals, and the maintenance costs. The plant is presumed to employ 1- 2 persons.

The outlined plant is expected to produce hygienic digested sludge for use in field cultivation. Compared to ordinary cattle manure, digested sludge provides the nutrients in a more easily accessible form for the plants being cultivated. Moreover, the co-digestion of the more nutrient rich fractions, increase the nutrient value of the digestate, when compared to cattle slurry alone. The sales price of digested sludge is excluded from the models presented.

The incomes of the plants comes primarily from the sold vehicle fuel (Model 1, 2), but also the aspect of possible gate fees and receiving payments is discussed (Models 1*, 2*). The annual income from the sold vehicle fuel (1.2 €/l) to external consumers has been estimated to reach the following levels, calculation model 1: €223,000 (when the possible gate fees and receiving payments are included: €280,000) and calculation model 2: €340,000 (when the possible gate fees and receiving payments are included: €400,000). The treatment of the manure fractions would be subject to a charge (€4/t) and the plant would pay a receiving price for the green fodder supplied to the digestion process (€5/t), the annual gate fees for the Model 1*: €55,000 would be and for the Model 2*: €60,000.

The plant's annual expenses consist of the investment costs and the plant's annual operating costs. The total costs of calculation Model 1 amount to €288,000/a (If the possible gate fees and receiving payments are included; €300,000), and those of Model 2 to €322,000/a (If the possible gate fees and receiving payments are included; 323,000). An interest rate of 5% has been used in the models' profitability calculations for an operating period of 10 years, which means that the annual investment costs will be €214,000. The starting point of the additional financial support for the investment has been estimated as 50%, according the previous cost-effectiveness studies for such heat and electricity producing biogas plants [19, 20]. So, the annual investment cost for the supported financing would be 107,000 €.

3 RESULTS AND DISCUSSION

According to the calculation models, a biogas plant investment producing only vehicle fuel with a capacity of 19,500 t/a will be profitable with Model 2, with or without gate fees included (Figure 1).

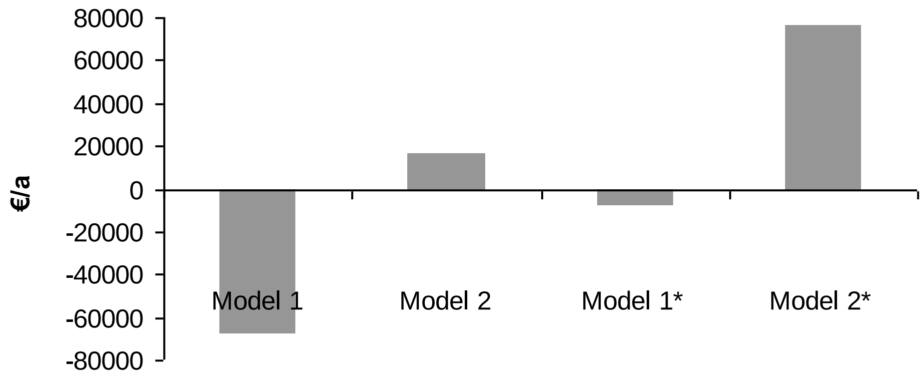


Figure 1. Annual profitability of the calculation models. Model 1 includes cattle slurry (17,000 t/a) and green fodder (2,500 t/a) and Model 2. cattle slurry (14,000 t/a), green fodder (2,000 t/a), chicken- (2,500t/a) and horse manure (1,000 t/a). Model 1 and 2* Includes the gate fees and receiving payments from the materials.*

Model 2 would be profitable also with the lower support level (42%), when compared to the such plant producing heat and electricity (Cost-effective support level > 50%; [19, 20]). Moreover, if the gate fees and receiving payments are perceived (Model 2*), the threshold of the support level needed would be < 20 % (Figure 2.). Gate fees obtained from the material reduce notably the amount of investment supports, but do not remove it entirely (Figure 2).

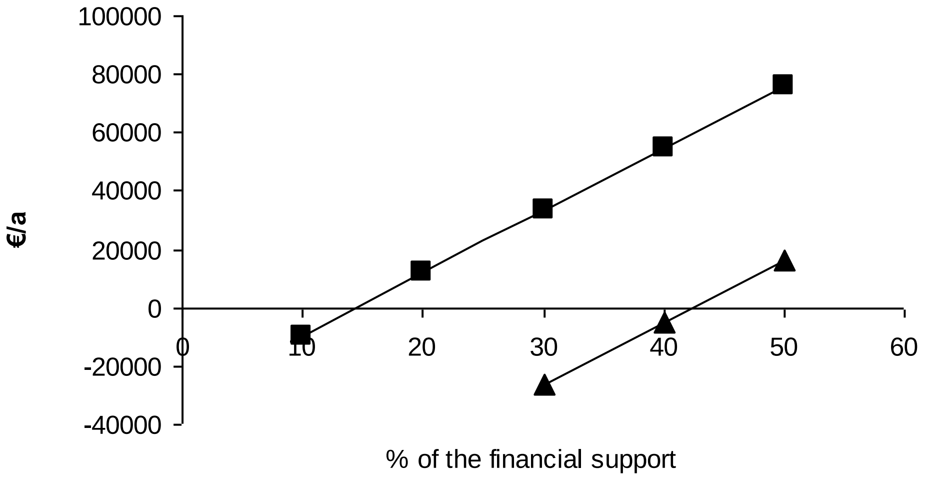


Figure 2. Model 2. annual profitability in a function of the financial support level of the investment (%). Model 2: Vehicle fuel production included (▲); Vehicle fuel, gate fees and receiving payments included (■).

Model 1, co-digesting only cattle slurry (17,000 t/a) and green fodder (2,500 t/a), was not economically beneficial even if the gate fee incomes was included (Figure 1). However, increased amount of green fodder (or corresponding material; +12 %) added to the process, would enhance the economic of Model 1* (Figure 3). This is in spite of the extra receiving payments paid for the supply of fodder (12,500 €/a). Without the gate fee procedure Model 1 is not economically beneficial in vehicle fuel production with such a material characteristics, relations and technical solutions used in the present study.

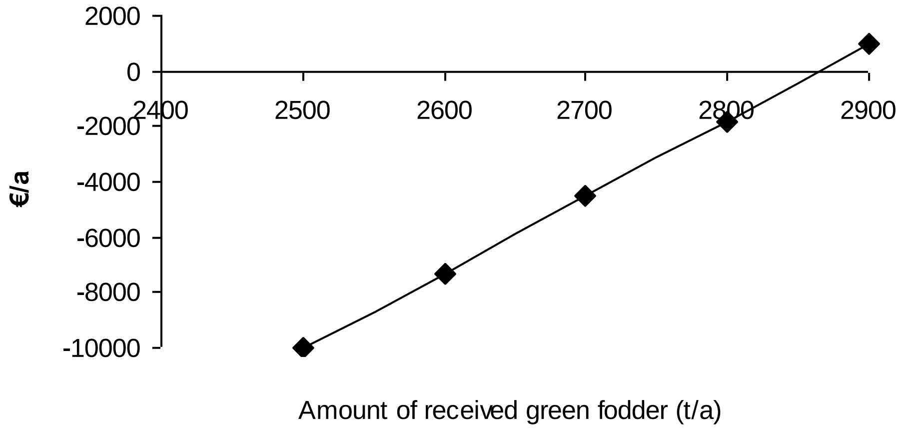


Figure 3. Model 1 and annual profitability in a function of the increased amount of the received green fodder (t/a).*

This short comparison shows the affect of the main characteristics of the feed-materials related to the cost-effectiveness. It should be noted, that the present biogas plant produced only vehicle fuel, when both the heat and the electricity was bought from general markets (see 2.3). Depending of the case (and the possible synergy benefits from the surrounding environment), it may be economically more beneficial to produce at least part of the heat and/or electricity to the own use of the biogas plant. This would approximately decrease the maintaining costs of such a plant by 13,000–59,000 t €/a, but increase the investment costs from 20 t to 200 t (depending is the investment CHP –unit or only heat boiler).

Another important point is the optimisation of the gate fees and receiving payments. If the biogas plant takes material from the industry (i.e., food processing industry wastes and by-products) and/or municipality (i.e. biowaste, sewage sludge), the gate fee payments are about 4-5 times higher, when compared to the tax of the animal manures used in the Model 1* and 2* (4€/t). However, this would also increase both the investment- and operational costs, when extra pre-treatments may be needed (i.e., hygiene treatment and/or crushing treatment). Also, the hygienic quality and the content of digestate may change less suitable to be utilized in renewable fertilizer in the fields.

Unlike studies with such centralised farm-scale biogas plant producing heat and/or electricity to the sale

(Soininen et al., 2012, 2013), vehicle fuel plant could be economically beneficial without the gate fee payments from the treatment of the materials. However, vehicle fuel production requires more for the location of the biogas plant that all the vehicle fuel produced will be utilized in the traffic use.

4 CONCLUSIONS

In terms of plant operation, an extremely significant role is played by the received in-feed materials' methane production potential and the gate fees obtained. Thus, it is highly important to obtain the low-cost but high methane potential material for co-digestion. According to the present examples, biogas conversion to the vehicle fuel seems to be economically more beneficial than heat and electricity production of our previous studies. The analysis indicates that, when using the initial values in question, the income generated by biogas plant based energy (i.e., vehicle fuel production) will be sufficient to cover the plants' annual investment and operating costs at the current energy price level. However, without support and/or gate fees this is not possible.

5 REFERENCES

[1] Luste S. (2011): Anaerobic digestion of organic by-products from meat processing industry – The effect of pre-treatments and co-digestion. 2011. Publications of the University of Eastern Finland. Dissertations in Foresty and Natural Sciences. ISBN 978-952-61-0522-2

[2] Holm-Nielsen J.B., Oleskowicz-Popiel P., al Seadi T. (2007): Energy Crop Potentials for Bioenergy in EU-27. In IWA (Eds.) proceedings of the 15th European Biomass conference, Berlin, Germany.

[3] Holm-Nielsen J.B., al Seadi T. Oleskowicz-Popiel P. (2009): The future of anaerobic digestion and biogas utilization. Biores Tech. 100: 5478-5484.

[4] Vänttinen V.H., Tähti H., Rasi S., Rintala J. (2009): Biokaasuteknologian alueellinen hyödyntämispotentiaali Keski-Suomessa. Jyväskylän Yliopiston Bio- ja ympäristötieteiden laitoksen julkaisuja. https://jyx.jyu.fi/dspace/handle/123456789/23570

[5] Ahring B., Ibrahim A., Mladenovska Z. (2001): Effect of temperature increase from 55 to 65°C on performance and microbial population dynamics of an anaerobic reactor treating cattle manure. Wat Res. 35: 2446-2452.

[6] Amon B., Kryvoruchko V., Amon T., Zechmeister-Boltenstern S. (2006): Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agr Ecosyst Environ. 112: 153-62.

[7] Angelidaki I., Ahring B. (2000): Methods for increasing the biogas potential from the recalcitrant organic matter contained in manure. Wat Sci Tech. 41: 189-194.

[8] Lehtomäki A., Huttunen S., Rintala J. (2007a): Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio. Resour Conserv Recycl. 51: 591-609.

[9] Mladenovska Z., Hartmann H., Kvist T., Sales-Cruz M., Gani R., Ahring B. (2006): Thermal pre-treatment of the solid fraction of manure: impact on the biogas reactor performance and microbial community. Wat Sci Tech. 53: 59-67.

[10] Møller H., Sommer S., Ahring B. (2004): Methane productivity of manure, straw and solid fractions of manure. Biomass Bioenerg. 26: 485-495.

[11] Nielsen H., Mladenovska Z., Westermann P., Ahring B. (2004): Comparison of two-stage thermophilic (68°C/55°C) anaerobic digestion with one-stage thermophilic (55°C) digestion of cattle manure. Biotech Bioeng. 86: 291-300.

[12] The European Parliament and the council of the European Union, 2009. Regulation (EC) No 1069/2009 of the European Parliament and the council of the European Union laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-product regulation). OJEU L300/1.

[13] Luste S., Soininen H. (2011): Anaerobic co-digestion of chicken manure, cattle slurry and vegetable wastes from a food industry, FINBIO publication 51. In: Book of Proceedings (CD) of the International Nordic Bioenergy 2011, Conference held in Jyväskylä, Finland.

[14] Luste S., Soininen H. (2012): Anaerobic co-digestion of chicken manure – Effect of material relations in feed mixture and hygienization on biogas production. Poster presentation and in Proceedings of 20th European Biomass Conference and Exhibition 2012, Milan, Italy.

[15] Luste S., Soininen H., Ranta-Korhonen T., Seppäläinen S., Laitinen A., Tervo M. (2012): Biokaasulaitos osana energiaomavaraista maatilaa. Mikkelin ammattikorkeakoulun julkaisusarja A: Tutkimuksia ja raportteja, ISBN 978-951-588-352-0

[16] Luste, S., Soininen, H., Seppäläinen, S. 2013. ESBIO-hankkeen loppujulkaisu, Energiaomavarainen maatila. Helsingin yliopiston julkaisusarja. Etelä-savossa saatavilla olevien orgaanisten materiaalien soveltuvuus biokaasulaitoksen raaka-aineeksi – metaanintuottopotentiaalit, yhteismädätys ja hygienia, ISBN 978-952-10-6530-9

[17] Soininen H., Kiukas I., Mäkelä L. (2007): Biokaasusta bioenergiaa eteläsavolaisille maaseutuyrityksille.

[18] Soininen H., Valkeapää A., Heinimö J. (2009): Profitability analysis of farm-scale biogas plants as part of agricultural farms' energy management. Proceedings (CD) of the 17th European Biomass Conference and Exhibition From Research to Industry and Markets, Hamburg, Germany.

[19] Soininen H., Luste S. (2012): Profitability case-analysis of co-operative biogas plant of several farms as part of agricultural farms' energy management in eastern Finland. Poster presentation and in Proceedings of 20th European Biomass Conference and Exhibition 2012, Milan, Italy.

[20] Soininen H., Ranta-Korhonen T., Luste S. (2013): ESBIO-hankkeen loppujulkaisu, Energiaomavarainen maatila. Helsingin yliopiston julkaisusarja. Tilakohtaisen biokaasulaitoksen kannattavuuslaskenta osana maatilojen energiataloutta Itä-Suomessa.

RECOVERY OF HIGH-VALUE FRACTIONS FROM POTATO INDUSTRY WASTE WATER

Juho Järvinen[1], Mikko Ahokas[1], Sanna Taskila[1]*

[1]Bioprocess engineering laboratory, University of Oulu, Oulu, Finland, P.O. Box 4300, 90014 Linnanmaa
**tel. 0400 871294, email: sanna.taskila@oulu.fi*

Approximately 100 000 tonnes of unused potato biomass is formed annually in Finland as a side-product of the potato refining industry. These side streams contain large amounts valuable components (proteins, fibers and starch) as dilute solutions. The purpose of this work was to study new feasible technologies to extract these components in separate fractions. Potato wastewater can be separated into so called potato fruit juice (PFJ) and a solids fraction. Solids contain mainly starch and fibers, while PFJ contains e.g. Proteins (~20 g per liter) and glycoalkaloids [1].

In this project, a laboratory made PFJ and industrial heated and non-heated streams were studied for potential utilization. An efficient concentration and purification scheme, involving vacuum evaporation, chemical precipitation and chromatographic steps, was developed for potato proteins. Protease inhibition (PI) and lipid acyl hydrolase (Patatin) activities were followed during the whole process. Heated water starch-rich streams were studied for other utilization purposes. Simultaneous concentration system with enzymatic or acid hydrolysis was developed for this material to produce high glucose syrup. In addition, the fiber content of potato peels was determined.

The enzymatic activity during the processing of non-heated PFJ was preserved during the whole process. In laboratory studies approximately 10 g of protein was extracted per kg of potato. Chemical precipitation of the concentrated protein solution (150-200 g/l protein) resulted in significantly purified PI fractions. These methods were proven to be applicable for industrial streams. Starch-rich stream was successfully concentrated into utilizable glucose solution.

With the developed purification scheme PFJ can be split into separate fractions of bulk storage protein (patatin) and valuable protein group of protease-inhibitors while removing toxic glycoalkaloids [2, 3, 4]. Patatin can be utilized in food and animal feeds. Protease inhibitors can be used in health-care products. The results obtained will also help to develop uses for the peel pulp and heated wastewater steams.

[1] Schieber A and Saldaña M (2009) Potato Peels: A source of nutritionally and pharmacologically interesting compounds- a review. *Glo. Sci. Books,* Food 3: 23-29.

[2] Ralla K, Sohling U, Suck K, Kasper C, Ruf F and Scheper T (2012) Separation of patatins and protease inhibitors from potato fruit juice with clay minerals as cation exchangers. *J. Sep. Sci.* , 35:1596–1602.

[3] Bártová V and Bárta J(2009) Chemical Composition and Nutritional Value of Protein Concentrates Isolated from Potato (Solanum tuberosum L.) Fruit Juice by Precipitation with Ethanol or Ferric Chloride. *J. Agric. Food Chem*. 57: 9028–9034.

[4] Alt V, Steinhof R, Lotz M, Ulber R, Kasper C and Scheper T (2005) Optimization of glycoalkaloid analysis for use in industrial potato fruit juice downstreaming. *Eng. Life Sci.,* 5: 562-567.

UTILIZATION OPPORTUNITIES OF BIOMASS MIXTURES BY THERMOCHEMICAL CONVERSION AND ANAEROBIC FERMENTATION IN HUNGARY

Tibor Vojtela; Hungarian Institute of Agricultural Engineering; H-2100 Gödöllő, Tessedik Sámuel road 4; + 36 28 511-632; vojtela.tibor@gmgi.hu
Péter Tóvári, Hungarian Institute of Agricultural Engineering; H-2100 Gödöllő, Tessedik Sámuel road 4; + 36 28 511-600; tovari.peter@gmgi.hu
László Fenyvesi; Hungarian Institute of Agricultural Engineering; H-2100 Gödöllő, Tessedik Sámuel road 4; + 36 28 511-600; fenyvesi.laszlo@gmgi.hu

Purpose of the work: Our purpose was to examine the energetic utilization i.e. biogas and syngas production of the mixture of sewage sludge and energetic grass. The direct combustion and separate digestion of these materials do not provide an adequate method for the utilization because of the slag formation and the low biogas yield.

Approach: The laboratory measurements were carried out in the Energetic Center of the Hungarian Institute of Agriculture Engineering. A custom-designed thermochemical gasification equipment has been developed which is suitable for gasification regarding the homogeneous medium sized fraction of woody and herbaceous samples by on a wide range of moisture range. For biogas measurements we also developed a laboratory size “batch” type system. In relation with gasification measurement the most important characteristics of the raw materials were investigated e.g. combustion properties as well as combustion properties of by-products. In terms of the biogas measurements the following properties were examined: substrate in homogeneity characterization, particle size, dry matter, organic dry matter content, C / N ratio, pH value as well as the biogas yield**.**

Scientific innovation and relevance: The topmost scientific innovation and relevance lies in that we provide an alternative solution for the utilization in connection with the two materials. This research is a very important factor, because it can provide a solution regarding the sustainable development and waste management topics. The development of the custom-designed measuring system is giving an extra scientific innovation which implies that a gasification device was constructed for the pyrolysis measurements. The principle of the device is a cyclone – a vortex flow chamber – which is heated. The fuel feed-in from above of a container which is equipped with screw feeding and the ash is collected in a bottom layer of water seal.

Results: From the experimental results concluded that the specimens dry basis heating value varies between 11 and 19 MJ / kg, which corresponds to the literature values in relation with the gasification measurements.. In case of combined digestion of the sewage sludge and energy crops 30% gas surplus was measured in laboratory reactor.

Conclusions: Our experimental results showed that the raw materials used for measurements can be produced relatively homogeneous biomass. This means that energy grass and sewage sludge mixture are suitable raw material for thermochemistry conversion and also for anaerobic fermentation thus helping in waste management and sustainability issues

PROCESSES FOR SOLID, LIQUID AND GASEOUS FUELS FROM BIOMASS

CFD SIMULATION OF BIOFUEL AND COAL CO-COMBUSTION IN A PULVERIZED COAL FIRED FURNACE

PERTTU JUKOLA and MARKO HUTTUNEN
VTT Technical Research Centre of Finland
P.O. Box 1000, 02044 VTT, Finland
perttu.jukola@vtt.fi, marko.huttunen@vtt.fi

ABSTRACT: Torrefied (thermally treated) biomass and pyrolysis oil are examples of processed, energy dense biofuels that might be utilized in energy production instead of fossil sources. Computational fluid dynamics code Fluent equipped with relevant user-defined sub-models was applied to simulate co-combustion of these supplementary fuels and coal in a full scale pulverized coal fired furnace with a capacity of 275 MWfuel. Biofuel shares up to 40 % by energy were considered. Changes in combustion process (heat transfer, burnout, NOx emissions) compared to normal coal operation were investigated and their influence in boiler performance analysed According to the results there are in general no drastic changes in the furnace process, hence utilization of the supplementary biofuels considered seems feasible from the combustion point of view. Evaporator heat transfer is predicted to decrease slightly especially in pyrolysis oil co-firing. Solid combustion efficiency remains at acceptable level in all cases. Share of unburned carbon fly ash is estimated to increase in torrefied biomass co-firing as a consequence of degrading particle fineness assuming integrated milling of biomass and coal. However total ash flow is remarkably lower. NOx emission reduction up to 20 % can be expected in co-firing cases with investigated biofuel shares.

1 INTRODUCTION

Various biomasses are main renewable sources of energy in combustion related energy production. In order to extend their applicability in traditional combustion applications such as pulverized fuel firing biomasses may be processed for e.g. better energy density, transportability, storability and combustibility. Torrefied biomass and pyrolysis oil are two examples of promising, refined biomass products that may play some role in energy sector in the future as production methods develop.

In torrefaction process the raw material is treated thermally at 200-300 °C in an inert atmosphere for 10-30 minutes [1]. Biomass dries and also undergoes some thermal conversion during treatment. The product is dry, energy densified “biocoal” that may be pelletized for further transportation and end use.

Pyrolysis oil is produced in the fast pyrolysis process, where biomass is rapidly heated up for example in circulating fluidized bed reactor and pyrolysed. Product vapours are then rapidly cooled and quenched to maximize oil yield with char and non-condensable gases as by-products. Pyrolysis liquids have quite different properties and composition compared to standard fuel oils therefore they need some extra care in end use [2].

In this work computational fluid dynamics (CFD) was applied to simulate co-firing of torrefied biomass (TF) or (pyrolysis) bio-oil (BO) with coal in a pulverized coal fired furnace. The goal of the work was to investigate the feasibility of above mentioned fuels to replace part of the coal from the combustion and furnace process point of view.

2 MODELLING APPROACH

The process simulated in computational fluid dynamic studies is a pulverized coal fired furnace of tangential firing/corner firing type. The normal full load of the furnaces is 275 MW_{fuel}. It is equipped with 12 low NOx coal burners on three levels, 8 gas/oil burners on two levels below and above them and over fire air system (OFA) for NOx control.

The commercial CFD code Fluent 12.1 along with VTT’s specific sub-models for pulverized fuel and pyrolysis oil combustion was used in simulations. Computational domain consists of burners, air nozzles and the furnace itself. Superheater region is included as far as the beginning of the 2nd pass. The volume is divided into a mesh of 1.6 million hexahedral cells for simulations. Furnace geometry and surface mesh are presented in figure 1.

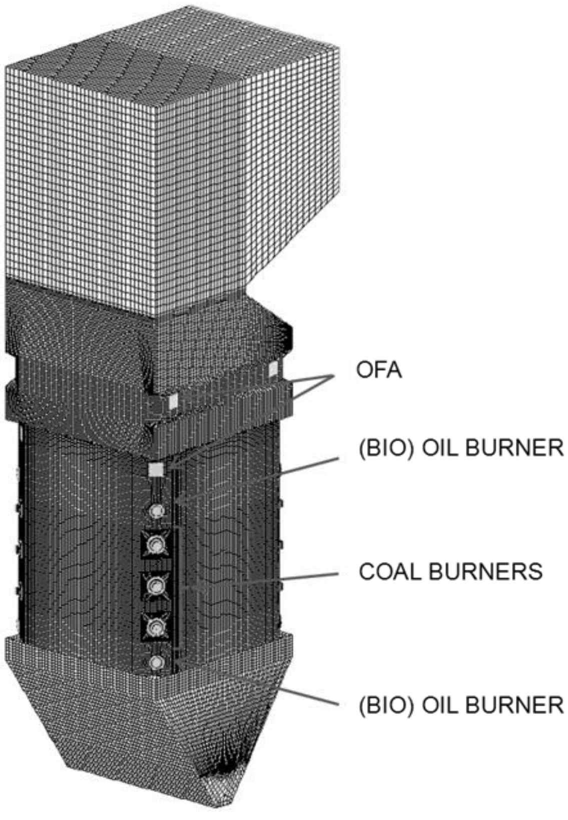


Figure 1. Furnace geometry and surface mesh

The three fuels considered in the simulations are Russian hard coal, torrefaction product from Finnish woody biomass (TF) and (pyrolysis) bio-oil (BO) from Finnish forest residue. Coal and TF are pulverized together in coal mills and fed to the coal burners as a mixture. Based on experimental milling results the coal particle fineness is assumed to degrade as TF share increase. Pyrolysis oil is injected into the furnace through atomizers located at each oil burner. Fuel properties used in simulations are presented in table 1. Coal and TF particle size distributions are shown in figure 2. Bio-oil atomizer is assumed to produce a droplet size distribution with Sauter mean diameter of 80 µm.

Table 1. Fuel properties

	Coal	TF
Moisture [w-%]	9.6	6.7
Ultimate analysis [w-%,dry]		
C	71.8	53.2
H	4.8	5.8
O	9.1	40.5
N	2.2	0.2
S	0.4	0.0
ash + others	11.7	0.4
Proximate analysis [w-%,dry]		
volatiles	35.7	82.5
char	52.6	17.1
FR (fuel ratio)	1.47	0.21
LHV [MJ/kg]	24.5	18.4

	Bio-Oil
Moisture [w-%]	24.0
Ultimate analysis [w-%,dry]	
C	56.6
H	6.2
O	36.9
N	0.1
S	0.03
ash + others	0.17
LHV [MJ/kg], wet	16.1
LHV [MJ/kg], dry	22.0

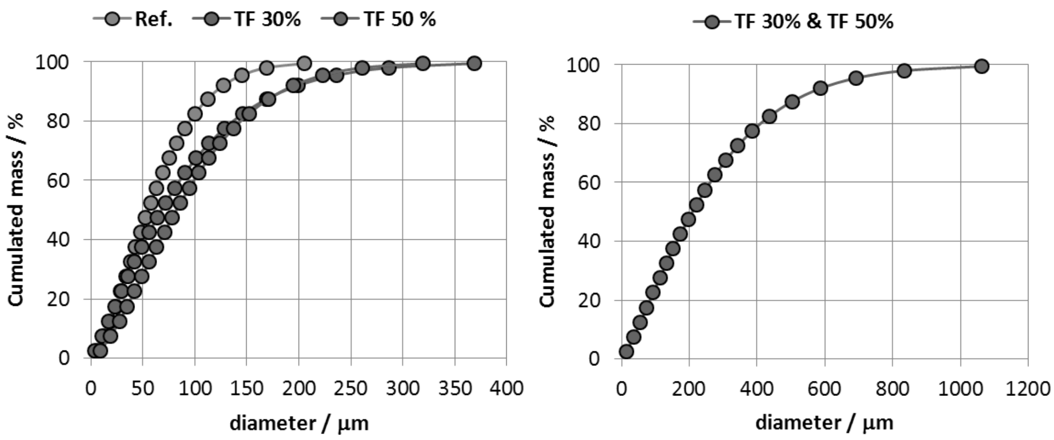


Figure 2. Particle size distributions of coal (left) and torrefied biomass (right) used in simulations. Coal fineness degrades as TF is added to the mills. In the BO case the original coal fineness prevails.

Co-firing was simulated with TF shares of 30 % and 50 % by weight (24% and 43% by energy) and with the BO share of 25-% by energy. They are compared to 100% coal combustion. As a sensitivity study the TF 50 wt-% case was also computed with the original coal fineness e.g. presuming separate crushing of TF. Case input parameters are collected in table 2.

Table 2. CFD case comparison

	Coal 100%	TF 30 wt-%	TF 50 wt-%	BO 25%
Fuel input [MW]	**275**	**275**	**275**	**275**
coal[%]	100	76	57	75
TF [%]	0	24	43	25
Total fuel flow rate [kg/s]	**11.2**	**12.1**	**12.8**	**12.7**
Total Stoichiometric Ratio	**1.3**	**1.3**	**1.3**	**1.3**
SR coal burner	0.8	0.8	0.8	0.8
SR oil burner	NA	NA	NA	1.0
SR burner zone	1.0	1.0	1.0	0.85
Flue gas O_2 (vol-%, wet)	**4.4**	**4.4**	**4.3**	**4.3**
Air flow rate [kg/s]	**123.5**	**121.2**	**119.3**	**122.1**
Flue gas flow rate [kg/s]	**133.3**	**132.2**	**131.3**	**133.6**

3 RESULTS

The main observation from the simulation results is that combustion does not change that much on a furnace scale compared to pure coal combustion especially in coal & TF co-firing. As TF share increases the flame stability seems to fade slowly as a consequence of larger average particle size decelerating ignition. According to the results flame stability is however still maintained with the TF shares up to 50 % at full burner load. At the same time evaporator heat transfer is weakened marginally and the furnace exit gas temperature at nose level tends to rise by some 0-20 degrees. Assuming original coal fineness in TF 50 wt-% case flame stability is excellent. Heat transfer is even enhanced compared to pure coal firing. In bio-oil firing there are two additional fuel input levels in use, such that fuel distribution becomes more even. This leads to decreased flame intensity in the main combustion zone and a bit reduced evaporator heat transfer rate. Evaporator heat transfer and furnace exit gas temperatures for each case are compared in figure 3.

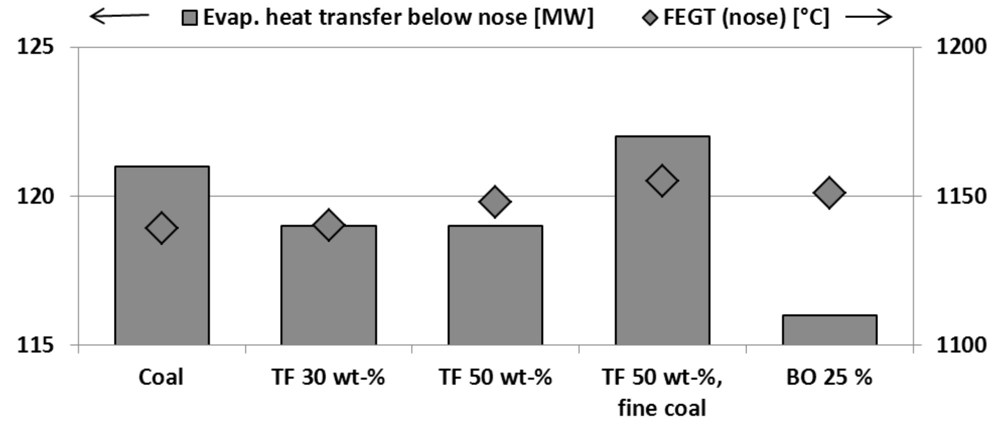


Figure 3. Predicted evaporator heat transfer and furnace exit gas temperature

Solid combustion efficiency remains at almost the same level in all co-firing cases compared to pure coal combustion There is however a predicted rise in fly ash unburned carbon (UBC) in TF 30% and TF 50% cases as a direct consequence of increased coal particle size due to degrading mill performance as TF is added to the mills. Mainly coal contributes to UBC, while TF and BO contain a lot of volatiles and only a small fraction of ash inorganics. Additionally biomass char is quite reactive. Reduced total ash flow explains the good combustion efficiency despite the increase in UBC. Combustion efficiency and fly ash UBC are presented in figure 4.

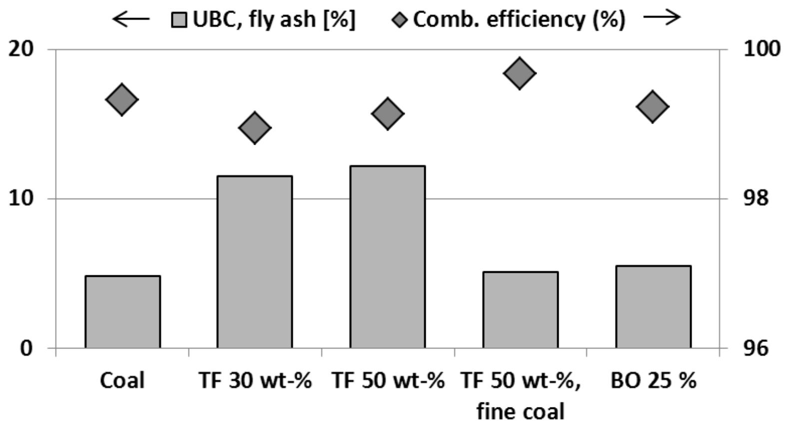


Figure 4. Unburned carbon in fly ash and solid combustion efficiency

In all TF co-firing cases the nose level CO concentration is predicted to be lower than in the coal combustion case but in all but one (the fine coal case) the outlet concentration is then higher by contrast. This difference is explained by continuing char particle burnout in the superheater zone (contributing to higher UBC as well). In the model CO is assumed to be the sole char oxidation product. It is however known that the share of CO2 as a product increases with decreasing temperature. That’s why the model may not necessarily predict the right CO trend in the upper part of the furnace and the predicted outlet concentrations are probably too high. The simulated nose level and domain outlet CO concentrations are shown in figure 5.

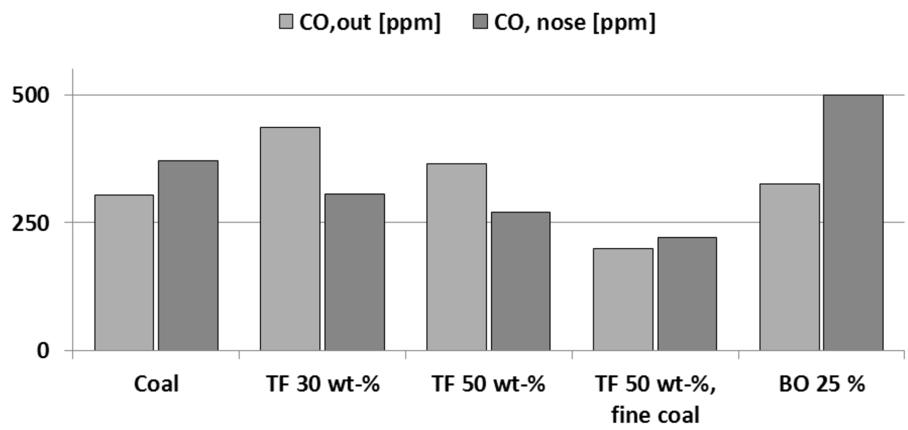


Figure 5. Predicted nose level and outlet CO concentration

According to the simulation results NOx emission would decrease in the modelled co-firing cases compared to coal combustion due to lower fuel N content in torrefied biomass and bio-oil. Emission reduction up to 20 % is predicted in BO co-firing and in TF 50 wt-% fine coal case. Anyhow the low-NOx burner seems to lose some of its NOx reduction efficiency, if particle size increases and coal is replaced by TF in co-firing. This is estimated to follow from fading flame stability and reduced near burner hydrocarbon concentration. Hydrocarbon radicals are effective NOx destroyers in reducing, high temperature conditions. The simulated NOx emission values are plotted in figure 6.

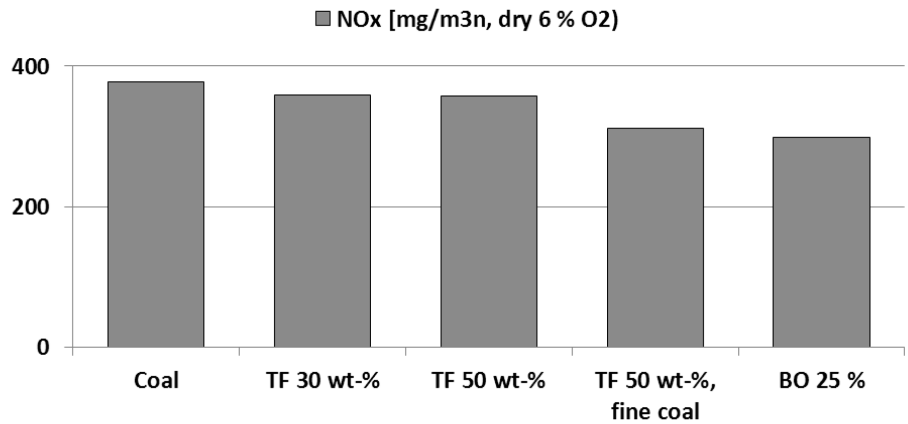


Figure 6. Predicted NOx emission

The results also indicate that risk for fouling and corrosion remains low at the main combustion zone in all simulated co-firing cases. Unreacted fuel is transported to the centre of the furnace. Evaporator walls are well protected by combustion and cooling air so that there is only a small concentration of particles and practically no unburned gases in the near wall region. In the two BO co-firing cases gas in the hopper zone is at reducing state, but on the other hand the temperature is lower there decreasing the corrosion/fouling risk. Instead some problems might arise in the superheater region with biomass originated ash and inorganic gaseous species involved especially as gas temperature is predicted to rise in the upper part of the furnace in co-firing.

4 CONCLUSIONS

From the combustion point of view it seems well feasible to replace coal by TF in the unit investigated with shares up to 50 % by weight. Also significant bio-oil co-firing is possible without major changes in the combustion phenomena. Flame stability could be an issue with even higher shares of TF or in partial burner load operation with notable TF content in fuel.

There should be no drastic change in furnace heat transfer although a small reduction in evaporator heat transfer rate (< 5 %) might be expected especially in bio-oil case. Furnace exit gas temperature before the superheater region is anticipated to rise slightly in co-firing.

According to the model TF co-firing is characterized by 1) combustion efficiency comparable to pure coal firing, 2) reduced total ash flow and 3) increased unburned carbon in fly ash, presuming coal mill performance degrades along with the addition of TF. Combustion efficiency and UBC can be positively affected by improving mill performance if possible or by e.g. applying separate crushing for TF. In bio-oil co-firing combustion efficiency and UBC are expected to be at the same level compared to coal combustion with decrease in fly ash flow.

Actual CO emission trend remains unclear due to modelling uncertainties, but no drastic increase is predicted.

NOx emission is reduced when increasing the share of biomass based fuel. Reduction up to 20% might be well possible in TF and BO co-firing.

Evaporator wall fouling/corrosion problems are not expected to increase in the furnace investigated. The superheater region might be more vulnerable in that sense with the simulated rise in FEGT.

5 ACKNOWLEDGEMENTS

The work was done as a part of the Torrefaction project in the Biorefine program of Tekes. The funding of Tekes, Fortum Power and Heat Oy, Helsingin Energia, Metso Power Oy, Metsä Fibre Oy, Pohjolan Voima Oy, UPM-Kymmene Oy, Vapo Oy and VTT is gratefully acknowledged.

6 REFERENCES

[1] Kiel, J., Torrefaction as an enabling technology for biomass co-firing, Status and ECN technology development, Workshop Recent Developments in Biomass Torrefaction, Espoo, Finland, 18 March 2011

[2] Oasmaa A. & Peacocke C., Properties and fuel use of biomass-derived fast pyrolysis liquids, A guide, VTT Publications 731, Espoo 2010

CURRENT STATUS OF SMALL SCALE BIOMASS CHP TECHNOLOGY DEVELOPMENT

David Linsley-Hood*^, Des McGinnes*, John Littlewood', Paul Wingeroth' & Andy Wiseman*
*Buccleuch BioEnergy Ltd, Edinburgh, EH22 2NA, UK,
'Cardiff Metropolitan University, Cardiff, CF5 2YB, UK
^Corresponding Author

ABSTRACT: The requirement for effective low carbon technologies for the generation of heat and electricity has been a much discussed topic. Of the many technologies that have been proposed, biomass Combined Heat and Power (bCHP) has been singled out as a topic of interest. The implementation of biomass CHP has had some success on a large scale in European and Scandinavian district heating systems, but to date few successful small scale (less than 2MW electric) systems have been implemented. This paper will investigate the key technologies and the levels of uptake and project success using the UK as principle example market, but with reference to key examples across Europe and Scandinavia

At present, there have been 42 small scale biomass CHP installations in the UK. Many of these have not succeeded. This has been for a variety of technical and financial reasons. These installations, along with other available technology developments have been evaluated and compared to demand requirements and available UK Government incentive schemes to assess the potential of their future implementation.

All of the technologies evaluated have some potential application. However with the exception of ORC systems, none have an established installation track record.

This paper is part of a wider doctoral research project into the viability of small scale biomass CHP in the UK, and the creation of a design criteria process and tool for the sizing and feasibility of bCHP systems for the UK.

KEYWORDS: Small Scale Biomass Combined Heat and Power (bCHP), Backpressure Steam Turbine, Organic Rankine Cycle

1 INTRODUCTION

The aim of this research is to evaluate the current situation related to the development of small scale biomass Combined Heat and Power (bCHP) systems (those below 2MWe) and the related regulatory and resource frameworks that exist and are intrinsically linked to the viability of the technology.

This study investigates the current status of both developers and installations of small scale biomass CHP installations across the UK, and looks at the number and current operational status of installations currently in place. This has been undertaken through detailed investigation of the key suppliers and developers of biomass CHP installations both in the UK and in Europe, and project data from installations where possible.

The aim of the research is to provide a benchmark for the current level of development in each of the technology areas and to highlight areas of future research in light of lessons learned.

This paper is produced as part of an ongoing Doctoral research project into the viability of small scale biomass CHP systems for the UK.

2 SCOPE

The decision to evaluate systems below 2MWe electricity generation is based on several factors. In initial research into the subject area, it was stated that the technology for bCHP systems above 2MWe was well established, using steam turbines. The technologies available below this are less well established, but display several new and innovative approaches and opportunities [1]. Therefore these technologies defined as worthy of future research.

The scale also relates to the assumed scale of useful thermal output under UK conditions. The use of district heating schemes is relatively low in the UK, at below 2% of delivered heat use, although studies say that there is scope for up to 14% [2], and therefore suitable thermal applications will be limited to single thermal applications and small emerging District Heat networks. These applications are assumed to be typically below 10MWth.

However there is some debate over the definition of bCHP scale. Dong et al. [3] defines Small-scale as systems below 100kWe and introduces Micro-scale systems as those which are domestic in output and have electricity outputs of 15kWe and below. Maraver et al. [4] describe prime movers of 2MWe to 200kWe as Small-scale, with specific reference to ORC technology systems, and also refer to Micro-scale systems as those below that. Quoilin et al. [5] also investigated small scale bCHP systems within the framework of ORC system applications. Their investigation concluded that small scale systems were limited by the ability to transport heat over long distances. Therefore these were defined as systems with thermal power of between 6-10MWth corresponding to 1-2MWe output. Kempegowda et al. [6] evaluate biomass CHP systems under Norwegian conditions, and defines Small-scale systems as those with total fuel inputs of less than 10MW. This equates to bCHP systems with electrical outputs of around 2-3MWe. However certain systems up to 10MWe are included in the study.

The IEA Bioenergy Agreement task 32 [7] investigated biomass CHP technologies. It separated its scope to cover technologies between 20MWe and 2000kWe (steam turbines) and those below 2MWe (Stirling engine and ORC systems). The study by VTT into Small-Scale Biomass CHP plant and District Heating [8] describes Small-scale systems as those below 20MWe and Micro-scale systems as those below 500kWe. However both of these investigations look at schemes with large scale established District Heating networks, and therefore have access to schemes with much larger thermal loads than those found in under UK conditions.

Based on these discussions, there is not one defined standard for the sizing of Small-scale bCHP systems. Therefore the decision to research systems of 2MWe and below is based on the utility in terms of UK conditions (which will be explored further in later chapters) and provides the widest range of new and developing technologies.

2 STATUS OF UK bCHP INSTALLATIONS

Over the past few years, a number of small scale bCHP installations have been installed across the UK. These span the full range of the technologies discussed in this study. A benchmark of the type and status of these installations is provided here. In total, there are 42 small scale bCHP installations known to be installed. Of these, the majority are Gasification (19) and Hot-Air turbine (9) type systems. A breakdown is given in Figure 1:

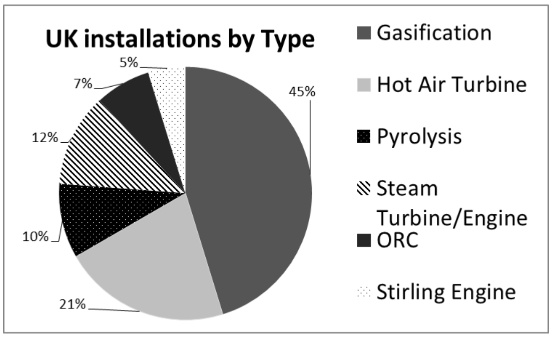


Figure 1. UK bCHP by type

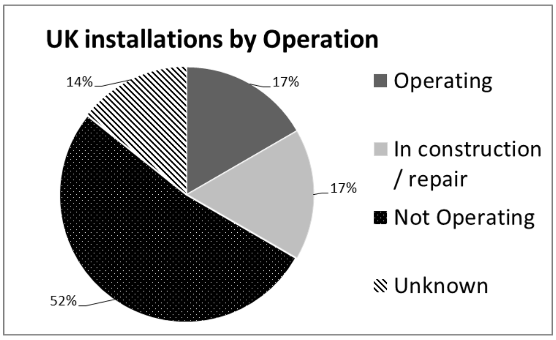


Figure 2. UK bCHP by operation

In Figure 2, the current operational status of the plants is given. At present, of the 42, only seven are known to be operating, with a further seven in construction, commissioning or repair. In total, there are 20 separate companies that have developed these installations. In terms of scale, 22 of these are below 500kWe, with only six being above 1MWe in scale. This demonstrates there has been a driver to develop smaller scale bCHP systems to meet UK operating conditions.

There is potential for the existence of certain backpressure steam turbine systems in industry or some additional experimental installations within companies or university campuses to exist, but it is believed that this represents the bulk of the type and status of UK bCHP installations.

3 OVERVIEW OF TECHNOLOGIES

3.1 BIOMASS CHP TECHNOLOGIES

In terms of the development of biomass CHP (bCHP) systems, there are two main processes by which the biomass can be used to create bCHP applications. Although these descriptions have been laid down previously and compared in many of the key reviews of the subject [3, 7-11], no standardized description of the split of these technologies has been developed, therefore the following differentiation will be used:

- The first is to convert the biomass into a gaseous or liquid fuel that can then be fed into a conventional reciprocating engine system. These shall be referred to as Advanced Conversion Technology (ACT) bCHP systems. The main technologies utilized here are Gasification and Pyrolysis processes. Fuel cells can also be utilized, but typically as second stage processes after the gasification process has occurred. Due to the range and complexity, and the lack of commercial examples, fuel cell systems are not considered here.

- The second is to combust the biomass directly, and then to use the heat to drive a thermal engine. The most common example is a steam cycle turbine, although other processes such as Organic Rankin Cycle, Stirling Engine and Hot Air Turbine are also used. These will be referred to here as thermal process bCHP systems. Other systems such as thermoelectric bCHP systems are currently in the developmental stages and not considered here.

Each of these technologies has certain advantages and disadvantages, and each have different operating conditions. Therefore a brief outline of each one will be offered below in order to evaluate their relative merits.

3.2 ADVANCED CONVERSION TECHNOLOGY (ACT) bCHP SYSTEMS

Advanced Conversion Technologies (ACTs) use thermal or chemical processes to reduce biomass fuel into a flammable gas, which can be combusted in a reciprocating or spark ignition engine, which in turns drives a generator. ACT's cover a wide range of processes; however the key areas can be broken down into Gasification, Pyrolysis and Anaerobic Digestion (AD). Due to the wet feedstock nature of the product, and significant differences in its operation and development, AD plants are not explored in this study.

3.2.1 GASIFICATION

Gasification systems are the most widely trialed system, as they offer the potential for easy integration with commonly used and well understood gas IC engine processes. There are three main types of gasification process:

- Downdraft Gasification
- Updraft Gasification
- Fluidized bed gasification

The processes detailed in the design and operation of these systems are well documented elsewhere [10], however the key variables involved in the design relevant to the evaluation here all relate to the fuel – both the moisture content and size of the material supplied to the process [12].

Gasification is of considerable interest due to the capacity for operating at electrical efficiencies of 25-40%, whilst providing heat at temperatures suitable for LTHW applications [13]. In the UK, 19 small scale bCHP biomass gasification plants are known to have been, or are being installed. Of these however, only there are thought to be currently operating, with a further three in construction. The range of technologies and installer/developers currently mean that the range of systems being offered is very wide, but each individual approach has a limited number of run hours in actual installation. This underpins one of the key issues with current gasification schemes, that there is limited investor confidence due to poor performance of the many trial plants, but therefore limited ability to trial new systems. The 19 UK installations span eleven companies, with all but four companies having a single trial and demonstration plant which are being used to attempt to win further work or test their specific design an operation processes. Three companies are currently promoting packaged gasification units as turnkey solutions to meet a current appetite for modular skid mounted biomass systems; however these too are only at the development and demonstration stage. On the continent and Scandinavia, there are several systems that have been installed and have operated with more success [8, 14]. However these are generally limited to the larger end of the market (>1MWe) and utilize fluidized bed gasification processes.

There has been considerable research undertaken into the various aspects of designing and operating biomass gasification systems [13-17]. However the key limiting factor to their operation still appears to be the ability to deal with variations in fuel quality. Even small changes in the moisture content can affect the production of tars in the Syngas and have knock-on effects through the production chain [17]. Therefore a high specification of fuel managed to very tight boundaries is required. There is possible scope for the use of Torrified biomass fuel, if this becomes financially viable to produce, as this will provide a more standardized input fuel product.

3.2.2 PYROLYSIS

The market for Pyrolysis systems is much smaller, with four systems installed in the UK, all of which are currently though to be either decommissioned or mothballed. There is a fifth firm which has had some success in the continent who are keen to promote system development in the UK, but at present, no systems are thought to be in development.

At a research level, there is considerable interest in the development of multi-stage Advanced Combustion processes, to produce finely balanced mixtures of bio-char, bio-oil and syngas through control of temperature and airflow [11]. The aim being to produce an energy hub arrangement capable of producing both CHP fuel and transportation fuel [18]. At present, all of these projects are in the research and development stages.

3.3 DIRECT COMBUSTION (DC) bCHP SYSTEMS

Biomass combustion on the other hand is much more straightforward. The biomass is delivered into a combustion chamber with the stoicyometry controlled to create complete combustion. The fully combusted gasses, currently at anywhere between 600-1000^{o}C are then passed through a series of heat exchangers to transfer heat into the medium to be used for heat extraction, this can either be [10]:

- Low Temperature Hot Water (LTHW)
- Medium Temperature Hot Water (MTHW).
- Thermal Oil (TO).
- Steam

In terms of generation system, this leads to four main type of generation process:

- Steam turbine
- Organic Rankin Cycle (ORC)
- Stirling Engine
- Hot air turbine

Each of these technology approaches have been tested at some level for their viability as small scale bCHP systems.

3.3.1 STEAM

Steam turbines are the mainstay of large power plant generation systems, and represent the most well understood and established electricity generation system, regardless of the fuel used to drive them. They are the most common type of Rankine heat engine, and use the thermal energy generated from the combustion process to raise water to high pressure steam in either smoke tube boilers (up to 27-32 BarA) or water tube boilers (typically up to 110-131 BarA) [19]. This high pressure steam is then injected into a steam turbine, where both the push of the high pressure steam on the blades, and the pressure drop caused by condensation after the turbine creating a pull on the blades, cause the blades to turn at very high speeds [20].

Traditionally, the steam turbine system is used in conjunction with a superheated steam boiler running at very high pressures. This ensures the most energy capture form the steam whilst maintaining the steam in its vapour form to reduce wear on the turbine. This is the process of operation for most commercial fossil fuel generation systems, and the waste heat is from either low pressure or sub-atmospheric steam as it condenses after the turbine system and either recovered through a LTHW or MTHW District Heating system, or vented to atmosphere through cooling towers [20].

Although the technology is well understood, it is widely regarded to be limited to large installations, over 2MWe, with installations below this scale being considered to be not economically viable. However the economics for these types of installation have changed recently, with a series of manufacturers commercializing small scale turbines in the 100-1000kWe range, and below.

In the UK, the low level of DH network penetration means the application for these large steam systems feeding low and medium temperature systems is relatively small. However there is considerable steam used as process energy, and it is possible through the use of backpressure steam turbines to extract this energy while still providing useful process steam. Several manufacturers are producing smaller turbines at the 5 to 10t/h steam range (roughly equivalent to a 3 to 6MW biomass boiler) capable of utilizing this level of steam flow while providing 2-8BarA on the output side. These systems can produce in the region of 100-250kWe. There are two manufactures producing smaller systems capable of operating in the 2-5t/h steam range producing 30-100kWe, however the economic advantages of this is highly dependent on site energy purchase price. An overview of products from the five main suppliers of backpressure turbine systems is given below in Table 1.

Table 1. Backpressure Steam turbine system data. Source: Supplied in commercial confidence

Electrical Output (Nett) kWe	Steam flow t/h	Steam input BarA	Steam Output BarA	H/E ratio % (approx)
48	3	26	9	3%
72	3	26	9	4%
165	9	26	9	3%
194	8	27	4	4%
200	8	28	9	4%
234	11	23	10	3%
250	9	28	9	4%
404	12	28	9	5%
660	17	28	9	6%

The cost of these backpressure steam turbine systems is relatively low compared to alternative bCHP turbine costs, as is shown in Figure 3, with system costs shown in Figure 4. However the system costs benchmarked against kWe produced are considerably higher, representing the low H/E ratio available. In these situations, the integration of the steam turbine system is a low part of the entire biomass installation (5-10% of total system capital cost) and has relatively low impact on the financial viability of the system, based on current UK financial conditions for renewable energy systems. However changes to either the Renewable Heat

Incentive (RHI) or value of Carbon may change the economics significantly.

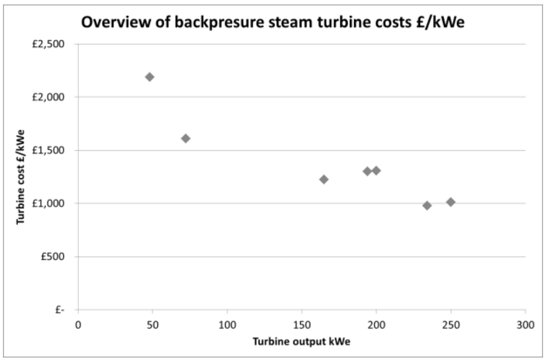


Figure 3. Steam Turbine costs £/kWe

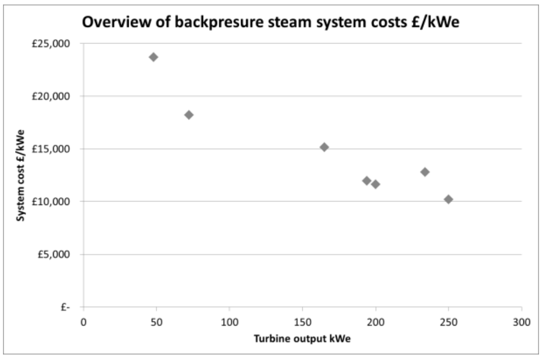


Figure 4. Steam system costs £/kWe

Of the 43 UK based bCHP installations, four are steam turbine systems and one is a Spilling Steam engine. All but one of these are believed to be operational. With the exception of the Spilling Engine, they are all close to the 2MWe level, showing the prevalence for larger systems in the current industry.

On the domestic scale, the only currently produced domestic scale bCHP unit is a Floating-piston steam engine system. This system operates at 1.5kWe and 16kWth (H/E 3:32). This system operates on wood pellets. Although none are currently known to be installed in the UK, the manufacturer states that there are 25 in field trails across Europe [21]. Due to the system size, the £/kWe cost is much higher at around £12,700/kWe

3.3.2 ORC SYSTEMS

Organic Rankin Cycle (ORC) systems utilise a similar process to steam cycle systems, but instead of using water as their medium, they use an organic liquid. The mass transfer process is very similar to that of a steam turbine, however as the material used is not water, it can remain as a liquid at much higher temperatures, only converting to a saturated low pressure vapour (320^{o}C is a typical input operating temperature for larger ORC systems). It passes through the turbine, dropping in pressure and recondensing in a closed cycle, ready to repeat its travel through the process [1]. An overview of the ORC process is given below:

This low pressure operation has the benefit that the system does not require to operate at the same high pressures as Steam systems, and as such does not fall foul of the same pressure directive based operational monitoring requirements which require constant or 72hr supervision arrangements. ORC units are typically purchased as packaged units, making their installation quick and easy.

ORC units can currently be obtained in two main thermal bands:

- 320/150^{o}C heating side 80/60^{o}C cooling side
- 150/130^{o}C heating side 35/25^{o}C cooling side

These two bandings are a considerable simplification of the range of products available, but highlight the key options that have a significant impact on the design and operation of an ORC based bCHP unit.

The most common installation process to date is the larger units operating at the greater temperature range. These operate with input temperatures of 320oC and provide LTWH at 80/60oC flow and return. These systems typically operate with electrical efficiencies at around the 16-19% range [22, 23]. It is possible to alter the flow/return temperature settings of the cooling side to provide heat at higher temperatures, up to 100/80^{o}C, where this is required for integration with existing distribution systems. However this results in a drop in electrical efficiency against the 80/60^{o}C benchmark (a reduction of 1-2% in electrical efficiency can be expected). The converse is also possible, and if flow/return temperatures of 40/25^{o}C can be used, then there is an increase in the electrical efficiency to around 22-24%. Unfortunately there are very few applications for water at this temperature range (with the possible exceptions of some form of air heating systems), therefore these systems are typically only used as electricity only systems.

The use of Thermal Oil fed biomass ORC units are the most prevalent type of bCHP unit across Europe. At present there are in excess of 50 small scale bCHP units installed across Europe, all with considerable run hours and demonstrated reliability. The first recorded ORC bCHP system was installed in Admont, Austria in 1999, followed by production scale systems installed from 2002 onwards [24]. Currently there are two of these installations in the UK, although both have only been operating since 2012.

Although the use of these larger scale ORC bCHP units is proven and has numerous installations to prove its viability, there is a monopoly on system providers. The large majority of systems come from one single supplier. They have been successful in gaining market dominance through their ability to provide packaged systems and demonstrate reliable operation for 8000hr/year systems. This supplier accounts for three of the five current ORC installations in the UK, with two currently operating and one under construction.

There has been a second scale of ORC units that have entered the market recently that operate in the low-medium temperature input ranges. These units have been developed primarily for use in waste heat recovery applications, from waste condensate from steam systems, Air heat dumps and other temperature sources. These systems require input temperatures in the 160-140^{o}C range, and have a cooling cycle operating at the 20-40^{o}C range, typically using air fan cooling units. They are smaller than the higher temp ORC systems, operating at the 30-150kW range. However as the temperature ranges of these systems are smaller, there is less potential energy available and the resulting electrical efficiency of these systems are lower with typical values at around 6-10% [25]. The lower temperature cooling cycle again makes these system limited in their application for providing space heating except through low temperature emitters or air heat delivery, both of which are infrequent in sufficient volume to be viable in the UK.

To date, these systems have been used successfully on Waste heat applications from Geothermal systems and Internal Combustion CHP systems, and they have proved to be successful [25]. However despite two non-operational trial systems installed in the UK, there are no working examples of this scale of ORC units being installed to create biomass CHP systems.

The table below gives an overview of the ORC systems available from five separate manufacturers along with their comparative thermal and electrical operating conditions, and the Nett Heat to Electricity ratio.

Table 2. ORC turbine system data. Source: [22, 23]

Electrical output (Gross) kWe	Electrical output (nett) kWe	Thermal input kWt	Thermal output kWt	Input temp oC	Output Temp oC	H/E ratio %
30	27	300	255	150/130	40/25	9%
61	55	860	795	116/106	30/20	6%
125	101	980	821	130/1115	35/25	10%
200	187	1165	950	315/203	80/60	16%
300	280	1715	1390	315/207	80/60	16%
300	281	1650	1335	320/155	80/60	17%
372	334	3000	2632	140/122	30/25	11%
400	376	2180	1760	320/155	80/60	17%
600	578	3339	2689	312/132	80/60	17%
707	640	6970	6244	140/98.5	38/25	9%

In terms of the financial investment required, Figures 5 and 6 provide the costs for the ORC units (against their gross electrical output) and the system cost (against net electrical output, installed). Both show a steady decline in costs, with a small aberration between the 100-200kWe systems. This is caused by the shift between MTHW and TO boiler technologies, with the capital investment for TO biomass boilers being roughly 30-40% higher on average, with further increases at the smaller scale [19].

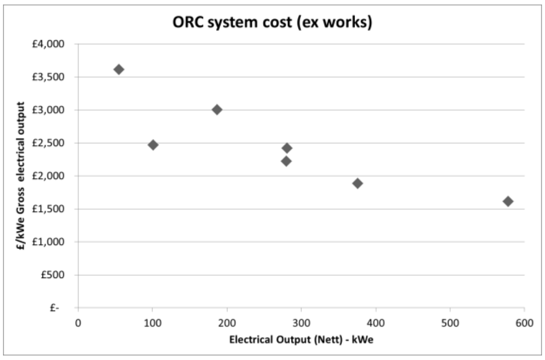


Figure 5. ORC Turbine costs £/kWe

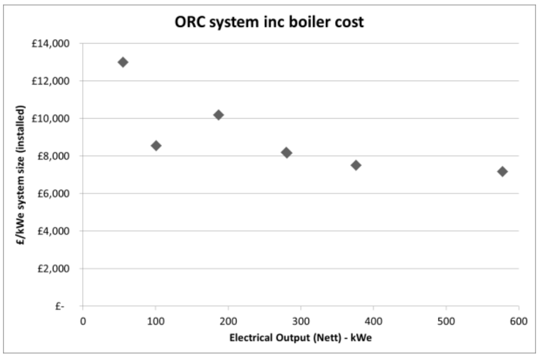


Figure 6. ORC system costs £/kWe

3.3.3 STIRLING ENGINE SYSTEMS

Stirling engine systems are closed cycle regenerative heat engines that operate typically using a permanently gaseous inert fluid. Their thermodynamic potential is high and can operate on greater temperature ranges than Rankine heat engine systems and with potentially higher electrical efficiencies. They are also indirect cycles and therefore can theoretically be incorporated into various stages of the biomass thermal conversion process [26]. For these reasons, there has been considerable research into the operation of Stirling engines for biomass CHP systems. However there have been several practical implementation issues that have limited the practical uptake of Stirling engine bCHP systems meaning there are few examples of these systems in actual use.

Commercial Stirling bCHP systems are currently limited to two operating scales: Stirling engines of around 35kWe for commercial systems, and 1-5kWe systems for domestic scale biomass boilers. The commercial scale system has been developed by a single Danish manufacturer who has been producing prototype systems for over 15 years. The first production model involved the integration of the Stirling engine heat exchanger into the secondary combustion chamber of a biomass furnace. This system had a thermal output of around 220kWth and the Stirling electrical output of 35kWe [7, 27] providing a H/E ratio of 1:6. Although this test system produced several thousand hours of operational run time, no other commercial installations are known to have been undertaken.

Recently, this design has been modified to improve the H/E ratio of the Stirling bCHP systems by separating the biomass combustion stages into gasification and then a combustion process. The Stirling engine is housed in the combustion chamber, allowing better thermal transfer, and the hot gasses are then used to produce the other thermal outputs of the bCHP system. This process has the advantages of easy maintenance of the Stirling engine as it is housed in a separate vessel. It also means that several Stirling engine combustion units can be attached to the single gasifier. As the gas is just being combusted rather than used in an IC engine or other process, variability in the gas quality is much less of an issue. This process provides a much higher H/E ratio with 140kWth to 35kWe (1:4) being delivered per unit, and the system comprising of four units in total.

Two of these systems had been installed, in Germany and on the Isle of Wight with a third in construction [28]. However the provider has ceased trading and this has jeopardized the development of this technology. The issue relates to the development of one of the installations, where the fuel delivered had higher levels of chlorine than had been designed for, and this caused significant corrosion in the installation requiring redesign and commercial liability issues [29]. The chlorine is thought to have occurred due to salt spray present in the fuel supply.

The installed cost of this system was estimated at £3m for the entire installation, equating to approx. £21,500/kWe installed [28]. This value is higher than comparable Steam and ORC systems, and delivers proportionately less thermal output. However this system does include an Absorption chiller unit which will have significantly affected the price. It is also unclear is this includes the civils works related to the construction of the energy center.

3.3.4 HOT AIR TURBINE SYSTEMS

Hot air turbine systems operate in a similar way to steam turbine systems, but by utilizing air as the energy transfer medium, there is considerably less pressure and monitoring requirements involved in the operation of the system, reducing supervision requirements. However the use of air requires considerably larger heat exchange surfaces and flow rates due to the much lower heat transfer capabilities of air compared to Steam. The use of Micro-turbines fed by high-pressure gas is well understood and is often used in transport applications such as helicopters, but also in the oil and gas industry for distributed generation applications [30].

Of the 42 small scale bCHP systems installed in the UK, nine were hot-air microturbine systems, supplied and installed by one firm. They also installed a tenth unit in Switzerland. This makes them the single largest installer of bCHP systems in the UK. These installations were undertaken between 2005 and 2008, however at present it is believed that only one is operational, and this is operated intermittently.

The units were designed as 100kWe 250kWth bCHP units, providing a proposed H/E ratio of 2/5 [31], which is among the highest described here. The unit cost was also competitive for its size at around £2500/kWe. Unfortunately the system was beset by technical problems related to the hot air heat exchanger, the turbine integration and the control system [32]. Manufacturing faults on the heat exchanger were allowing cold air to be drawn into the heat exchanger, lowering air temperature and reducing pressure. In operation this resulted in lower electrical outputs than expected (50-65kWe). The mass-flow through the Air-Water heat exchanger (HX) was also affected, with poor temperature performance on the thermal output requiring high circulation flow rates. This lead to maximum output requiring flow temps of 60/50oC across the HX [33].

In Europe and Scandinavia, other organizations have been researching the same principle and there are systems designed by Italian Swedish and Finnish developers attempting to redesign the hot air turbine concept [34-36]. No commercial data is available regarding these system, however they operate on quite different scales. The Finnish system is a commercial scale application operating at 100kWe and 300kWt – a H/E ratio of 1:3. It has been developed in association with research undertaken at Lappeenranta University of Technology (LUT) [34]. The Swedish system is a domestic scale system unit with a proposed rating of 7kWe and 17kWth – a H/E ratio of 7:17 or 41% [37]. If viable in test, this would give it the largest H/E ratio of any bCHP system.

4 CONCLUSIONS

The current status of bCHP systems across Europe is developing and has improved somewhat over the past few years. The use of ORC systems predominates the industry, especially where biomass CHP systems can be connected to LTHW DH systems. Due to the lack of this market in the UK, it has seen considerably slower uptake in the development of ORC bCHP systems. The use of Steam turbine and Steam Engine systems is common on the larger scale, but has not yet penetrated the UK market typically due to the requirement for smaller backpressure steam requirements for process steam.

In terms of the other technologies, all have shown some success at the demonstration level, but have been beset by technical and financial challenges that have limited their uptake and attractiveness to all but the most specialist applications and clients. There remains considerable work in order to establish mainstream consumer confidence.

All technologies have shown development over the past few years and there is movement across all fields for a reduction in size and system cost, even down to the domestic level. However there is not enough data available from extensive field trials to establish if these systems may be viable.

REFERENCES

1. Obernberger, I., et al., *New small scale Organic Rankine Cycle (ORC) technology (200 kw electrical) for decentralized biomass power and heat coupling facility*, in *Neue Klein-ORC-technologie (200 kWel) für Dezentrale Biomasse-KWK-Anlagen*. 2008. p. 133-149.
2. Pirouti, M., et al., *Energy consumption and economic analyses of a district heating network.* Energy, 2013. **57**(0): p. 149-159.
3. Dong, L.L., H. Liu, and S. Riffat, *Development of small-scale and micro-scale biomass-fuelled CHP systems - A literature review.* Applied Thermal Engineering, 2009. **29**(11-12): p. 2119-2126.
4. Maraver, D., et al., *Assessment of CCHP systems based on biomass combustion for small-scale applications through a review of the technology and analysis of energy efficiency parameters.* Applied Energy, 2013. **102**(0): p. 1303-1313.
5. Quoilin, S., et al., *Techno-economic survey of Organic Rankine Cycle (ORC) systems.* Renewable and Sustainable Energy Reviews, 2013. **22**(0): p. 168-186.
6. Kempegowda, R.S., Ø. Skreiberg, and K.Q. Tran, *Techno-economic Evaluations of Various Biomass CHP Technologies and Policy Measures Under Norwegian Conditions.* Energy Procedia, 2012. **20**(0): p. 1-10.
7. Obernberger, I. and G. Thek, *Techno-Economic evaluation of selected decentralised CHP applications based on biomass combustion in IEA partner countries -final report*, in *IEA task force 32*. 2004, Graz University of Technology: Graz.
8. Sipilä, K., *Small-scale biomass CHP plant and district heating*. 2005, Espoo: VTT. 129 p.
9. Salomón, M., et al., *Small-scale biomass CHP plants in Sweden and Finland.* Renewable and Sustainable Energy Reviews, 2011. **15**(9): p. 4451-4465.
10. Van Loo, S. and J. Koppejan, *The handbook of biomass combustion and co-firing*. 2008, London: Earthscan.
11. Zhang, L., C. Xu, and P. Champagne, *Overview of recent advances in thermo-chemical conversion of biomass.* Energy Conversion and Management, 2010. **51**(5): p. 969-982.
12. Brammer, J.G. and A.V. Bridgwater, *The influence of feedstock drying on the performance and economics of a biomass gasifier-engine CHP system.* Biomass and Bioenergy, 2002. **22**(4): p. 271-281.
13. Negro, S.O., R.A.A. Suurs, and M.P. Hekkert, *The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system.* Technological Forecasting and Social Change, 2008. **75**(1): p. 57-77.
14. Pereira, E.G., et al., *Sustainable energy: A review of gasification technologies.* Renewable and Sustainable Energy Reviews, 2012. **16**(7): p. 4753-4762.
15. Elder, T. and L.H. Groom, *Pilot-scale gasification of woody biomass.* Biomass and Bioenergy, 2011. **35**(8): p. 3522-3528.
16. Rentizelas, A., et al., *Comparative techno-economic analysis of ORC and gasification for bioenergy applications.* Energy Conversion and Management, 2009. **50**(3): p. 674-681.
17. Ruiz, J.A., et al., *Biomass gasification for electricity generation: Review of current technology barriers.* Renewable and Sustainable Energy Reviews, 2013. **18**(0): p. 174-183.
18. Isahak, W.N.R.W., et al., *A review on bio-oil production from biomass by using pyrolysis method.* Renewable and Sustainable Energy Reviews, 2012. **16**(8): p. 5910-5923.
19. Schranzer, M., *Email related to design and operation of Kohlbach Biomass boiler systems*, D. Linsley-Hood, Editor. 2013.

20. Boyle, G., *Renewable energy*. 2nd ed. ed. 2004, Oxford: Oxford University Press.
21. GmbH, B.E. *BISON Powerblock*. 2013 [cited 2013 11/08/13]; Available from: http://www.buttonenergy.at/_lccms_/_00062/bison-Powerblock.htm?VER=110716135709&MID=64&LANG=eng.
22. Senechal, S., *Email communication related to ORC system development*, D. Linsley-Hood, Editor. 2013.
23. Hellner, F., *Email communication related to the operation of Maxxtec ORC system*, D. Linsley-Hood, Editor. 2013.
24. Network, O., *Micro and small-scale CHP from biomass (>300kWe)*. 2004, VTT: Finland. p. 1-12.
25. Emerich, R., *Email communication related to the Electrotherm ORC system*. 2013.
26. Roberto, B. and M. Enrico, *Organic Rankine Cycle Turbogenerators for Combined Heat and Power production from Biomass*, in *3rd Munich Discussion Meeting "Energy conversion from biomass fuels - current trends and future systems"*. 1996, Turboden: Munich. p. 8.
27. Biedermann, F., et al., - *Operating Experiences with a Small-scale CHP Pilot Plant based on a 35 kWel Hermetic Four Cylinder Stirling Engine for Biomass Fuels.* - Proceedings of the 11th International Stirling Engine Conference.
28. Energy, T., *Waitrose Bracknell Stirling based Trigeneration system*, in *Enterprise M3 Case Studies*. 2012, TV EnergyForestry Commission. p. 2.
29. Waitrose, *Telephone communication with manager at Waitrose Store - Cowes*, D. Linsley-Hood, Editor. 2013.
30. Soares, C., *Chapter 3 - Microturbine application and performance*, in *Microturbines*. 2007, Butterworth-Heinemann: Burlington. p. 21-30.
31. Pritchard, D., *BIOMASS COMBUSTION GAS TURBINE CHP*, ETSU, Editor. 2002, DTI. p. 68.
32. Jolly, A., *Biomass CHP projects Review Report for WEBS*. 2009, Forestry Commission Wales: Cardiff. p. 12.
33. Linsley-Hood, D., et al., *The viability of small scale Biomass Combined Heat and Power (bCHP) for the UK - Initial findings from case study research* in *C92 - Energy in the City*. 2010, The Solar Energy Society: London South Bank University, London. p. 6.
34. Oy, E. *Ekogen Mini CHP*. N/A [cited 2013 11/08/13]; Available from: http://www.ekogen.fi/products.html.
35. Pantaleo, A.M., S.M. Camporeale, and N. Shah, *Thermo-economic assessment of externally fired micro-gas turbine fired by natural gas and biomass: Applications in Italy.* Energy Conversion and Management, 2013. **75**(0): p. 202-213.
36. Gaderer, M., G. Gallmetzer, and H. Spliethoff, *Biomass fired hot air gas turbine with fluidized bed combustion.* Applied Thermal Engineering, 2010. **30**(13): p. 1594-1600.
37. Compower. *Compower Products*. 2013 [cited 2013 11/08/2013]; Domestic scale hot air turbine bCHP units]. Available from: http://compower.se/.

EXPERIMENTAL INVESTIGATION OF A 45 MW CHP SPREADER STOKER BIOMASS BOILER

T. Florea[1], S. Caillat[2,3], M. Bonnin[1], C. Marty[1], M. Al Haddad[1]
[1] Leroux & Lotz Technologies, F-38320 Eybens, France
[2] Univ. Lille Nord de France, F-59000 Lille, France
[3] Mines Douai, CE, F-59508 Douai, France
tudor.florea@lerouxlotz.com, sebastien.caillat@mines-douai.fr, marine.bonnin@lerouxlotz.com, charlotte.marty@lerouxlotz.com, mazen.alhaddad@lerouxlotz.com

ABSTRACT: Measurement data within large biomass fired combustion facilities is a key factor in order to achieve an optimal design. Performing experimental measurements on such type of boiler is not a trivial task giving that, besides the extreme conditions within the furnace; the installation is in commercial operation. Thus, the goal of this study was to assess the feasibility of gas concentration measurements inside the combustion chamber, using materials and methods as simple as possible and without disturbing the normal operation of the boiler (*i.e.* continuous and stable heat and power production with respect to the demand of the grid). A water cooled probe has been developed for the gas sampling. The measured gas species inside the furnace were: O_2, CO_2, CO, NO_x, THC, CH_4 and SO_2. The results indicate that easy to use techniques for in-furnace gas measurements can be successfully applied to large scale biomass fired boilers with no impact on the plant operation. The in-situ gas sampling technique introduced here gives satisfactory results. The flue gas concentrations at the chimney were also measured. The retrieved data is currently used for operation parameters optimisation and as a support for CFD modelling.

Keywords: in-furnace measurements, gas sampling, spreader stoker

1 INTRODUCTION

The optimal design and the operation parameters for large biomass combustion facilities are quite difficult to define in nowadays context, where the required efficiency and pollutant emission levels become stricter every year, while limiting the use of feedback from existing installations. The tools used during the design and optimization process are evolving in consequence; for example, Computational Fluid Dynamics (CFD) is now widespread. However, the CFD introduces a certain degree of simplification, whether in boiler geometry or in physical models. Besides the large volume and the geometrical details of a full-scale boiler, experimental data is also needed, not only for the mathematical model validation, but also as a complementary tool for design and operation optimization. However, the measurements carried on a commercial boiler must not disturb its operation (*e.g.* instabilities or shutdowns must be avoided), its purpose being the continuous energy production. Such a strong limitation may reduce the retrievable experimental and operational data.

The present work allows enhancing the design and optimization process of large-scale biomass boilers. In order to achieve this goal several tools and approaches are developed. The first step is oriented towards the search of an experimental tool applicable to the investigated boiler, without disturbing its operation. Thus, experimental tools applied to a 45 MW_{th} spreader stoker biomass fired boiler are discussed here, with special emphasis on the in-furnace gas sampling.

The measurements allow, on one hand, an overall view of the solid and gaseous fluxes as well as operational parameters (such as air staging, temperature and flue gas composition at the chimney). On the other hand, in-furnace gas concentration measurements give valuable information about the local evolution of the combustion, which is required, for instance, to apply and enhance primary methods for pollutant abatement. Retrieving this data is quite a complex task, since, not only the boiler operation must be ensured, the extreme conditions within the combustion chamber (high temperature, combusting particles in the flow, fly ash and soot) require special attention. Moreover, the employed technique would have to be easy to use, portable and robust so that the time needed for the measurements is minimised. One of the reasons for that is linked to the boiler's dimensions, which can go up to several tens of meters in height for industrial facilities. Thus, in order to carry the measurements in the same conditions (for instance the boiler load), the measuring equipment must be easy to transport rapidly and safely from one measurement point to another.

There is abundant information in literature related to in-furnace measurements on laboratory scale devices, a few examples can be found in the studies carried by Wang *et al.* [1], Weissinger *et al.* [2] or Williams *et al.* [3]. Also, this type of measurements, have already been applied to small-scale woodchips grate fired boiler [4, 5]. The goal is to extend these techniques to large biomass fired boilers. The work of Brink *et al.* [6] and Vainio *et al.* [7] carried on a 107 MW_{th} BFB boiler is relevant. Brink *et al.* [6] tested two techniques for the gas temperature measurements, *i.e.* CO_2-absorption pyrometer and suction pyrometer. Vainio *et al.* [7] used an air-cooled probe for the gas sampling. In order to ensure a high quality of the gas

sample, their probe was equipped with a nitrogen quenching system and SF_6 tracer in order to determine the dilution ratio. Their results prove the feasibility of such measurements on large scale boilers. However, the measuring chain, especially for the gas analysis, could be difficult to manipulate around the boiler and requires special care (for instance because of the pressure gas cylinders). Hence, in the present study a simple design easy to use water-cooled probe was tested for the gas sampling, the aim being the fast and safe handling whilst ensuring a sufficient quality for the gas sample.
These results, together with the boiler's monitoring data and an extended mass balance, are used for the boiler optimisation and to validate the CFD modelling of this type of boiler.

2 MATERIALS AND METHODS

2.1 Boiler description

The investigated boiler is based on the spreader stoker technology and is used to provide superheated steam for CHP application. The rated thermal output is 45 MW_{th} with 92% minimum efficiency. This corresponds to 57 t/h steam flow rate at 90 bar pressure and 520 °C temperature. The gross electric output of the CHP plant can go up to 12 MW_{el}, while the gross heat output may reach 29 MW_{th}.
The schematic of the boiler is depicted in Figure 1. The fuel is feed thorough three chutes; at the bottom of each chute air is injected for the pneumatic feeding. The fuel particles carried by this air flow fly across the flame and fall on the travelling grate. During their flight the fuel particles are dried and partially devolatilised. Once on the grate, the fuel particles form a thin bed carried by the travelling grate. The remaining volatiles are then released and char is burned by the primary air introduced beneath the grate. The resulting ash is carried by the grate and fells into the ash pit from where is evacuated by a wet bottom ash extraction system.

The volatiles are gradually mixed and burn with overfire air, which is introduced at different heights of the furnace. Hence, the air staging ensures, besides an enhanced mixing, a uniform temperature distribution, thus limiting the thermal NO_x formation. A selective non-catalytic reduction (SNCR) system - with urea injection - is also installed for NO_x reduction and is running only when the fuel nitrogen content exceeds 0.4%wt on DAF basis.
Once the combustion achieved, the hot combustion gas passes through four steam superheaters and four economisers, where the heat is transferred to the steam.

The flue gas exiting the boiler flows thorough a multicyclone and a bag filter, in order to remove the dust particles, before reaching the chimney. Moreover, in order to enhance the char burnout, the coarse fly ash particles collected in the boiler's hopper (situated at the boilers exit) are recycled.

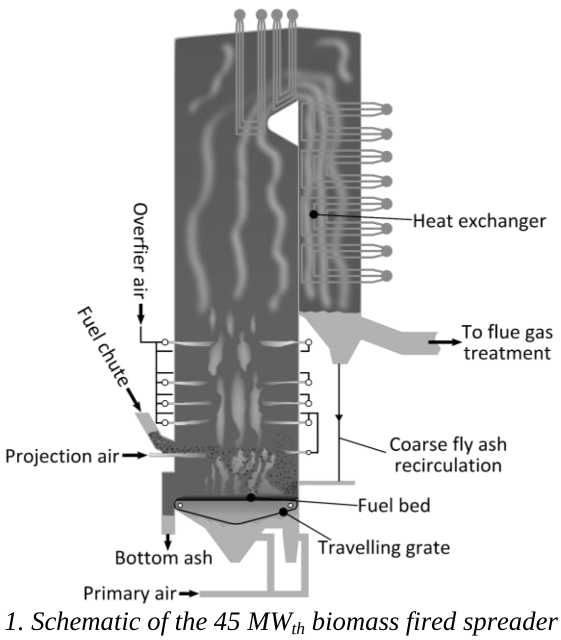


Figure 1. Schematic of the 45 MW_{th} biomass fired spreader stoker

2.2 In-situ gas sampling probe

The gas sampling probe used for the in-furnace measurements, shown in Figure 2, is made of three coaxial stainless steel tubes. The inner tube is used to transport the gas from the sampling point in the furnace to the heated line and finally to the gas analysing system. The last two tubes contain the water used for cooling. The effective length of the probe is 2.6 m, which can cover half of the furnace width. Before entering the heated line, the gas sample passes first thorough a micro-cyclone in order to remove the dust particles that may be entrained with the gas sample.

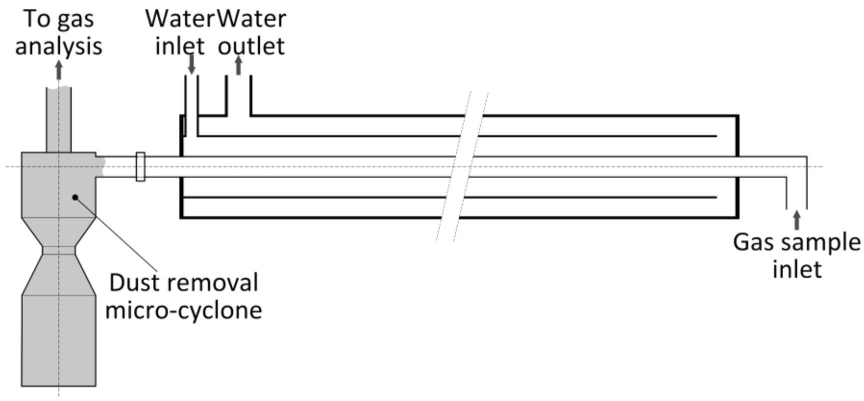


Figure 2. Schematic of the gas sampling probe

The main advantage of this design is that it is easy to build. Moreover, it needs only a water supply, which is usually available on site. However, since the gas sample is not quenched and the inlet water temperature is not controlled, the quality of the gas sample may suffer and thus the uncertainty could became important.

The flue gas sampling in the chimney was carried out using standard isokinetic heated probes.

2.3 Gas analysis

As stated before, the gas concentration was measured in parallel inside the furnace and at the chimney level. Hence, two gas analysis measurement chains were used. For the in-furnace measurements, the gas concentration was determined using the following devices:

- In-situ gas sampling probe, as described in the previous subsection;
- 25 m heated line;
- gas conditioning system (filtering and water vapour removal);
- gas analyser:
  - paramagnetic cell for O_2 analysis;
  - infrared cells for SO_2, CO_2 and CO analysis;
  - chemiluminescence cell for NO_x analysis;
- flame ionization detector (FID) for total unburned hydrocarbons (THC) and CH_4 analysis.

The measuring chain used at the chimney contains:

- 2 isokinetic heated probes;
- heated lines;
- sparging cells for SO_2 and HCl analysis;
- condensation cell for water vapour concentration measurement;
- quartz filters for solid phase sampling (dust level, PAH and VOC screening concentration measurements);
- gas conditioning system (filtering and water vapour removal);
- gas analyser:
  - paramagnetic cell for O_2 analysis;
  - infrared cells for CO_2 and CO analysis;
  - chemiluminescence cell for NO_x analysis;
  - FID for THC and CH_4 analysis.

The minimum expected relative uncertainties for the gas concentration measurements are given in Table 1, for each species. These values may be actually higher, especially for the in-furnace measurements.

Table 1. Relative uncertainties for gas concentration measurements

Species	O_2	CO_2	NO_x	H_2O	CO	VOC	CH_4	SO_2	Dust	PAH	HCl
Relative uncertainty* (%)	10	10	15	15	20	20	20	20	20	20	25

* Confidence interval is 95%

3 EXPERIMENTAL SETUP

The measurements were carried for three different loads of the boiler: 100, 80 and 65% of the rated output. For the in-furnace gas concentration measurements, the gas was sampled at three points of the combustion chamber, as shown in Figure 3. The first point (P1) is situated at the fuel chute level about 1.2 m above the grate, on the left hand side. The other two points (P2 and P3) are located bellow the last overfire air injection and approximately 3 m above P1 point. They are disposed symmetrically with respect to the longitudinal axis. The aim was to obtain a species concentration profile at these levels. Unfortunately, due to the operational constraints, the gas was sampled in only one point, close to the furnace wall, for each of the three ports.

Standard ports were used for the measurements at the chimney (gas sampling, temperature and flow rate). The complete VOC screening was performed only at full load. The fuel sample was collected on the belt conveyor, situated at the exit of the fuel storage building, while the bottom ash was sampled within the storage bins. A system of extracting screws allows the separate sampling of the fly ash from multicyclone and bag filters respectively.

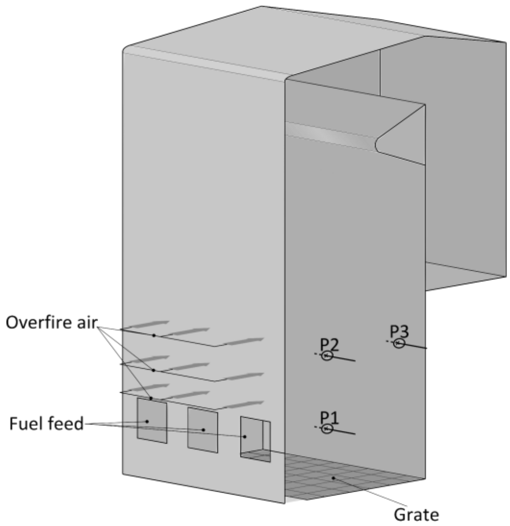


Figure 3. Measuring points inside the furnace

4 RESULTS AND DISCUSSION

4.1 In-furnace gas concentration

Given the operating conditions, the gas concentration could be measured only at the point P1 at 65% boiler load. For all the other investigated boiler loads, the gas sampling was successful, the measured concentrations being listed in Table 2. The duration of sampling was of about 5 minutes, the values given in Table 2 being averaged over this time interval.

One first observation is that the measured values are insensitive to the boiler's load for the point P1, which is close to the grate surface and situated on the fuel particles trajectory. At this level, the CO concentration reached the analyser upper limit (*i.e.* 5%vol.). As expected for biomass, the CO is the major volatile specie, together with CH_4, the rest being represented by non-methane hydrocarbons. The NO_x concentration shows relatively low values at this level compared with the results obtained for the point P2. This is mainly due to the lower oxygen yield. The slight variations of the NO_x concentration at point P1 may be due to the fuel composition and temperature fluctuations. Unfortunately neither of these two parameters is known. However, one can state that at this level of the furnace, the main source of nitric oxides is the fuel nitrogen. The above considerations may be applied also to the SO_2 concentration, which is quite high in this region of the furnace.

Based on the values measured in the point P2, compared to those recorded for the point P1, while going upwards within the furnace, the gas phase combustion intensity increases as the overfire air is injected. This is supported by the fact that the concentration of the combusting gases decreases drastically between these points, for the same boiler load. Moreover, when the boiler load increases, the values recorded at point P2 for the combusting gases and SO_2 concentrations suffer significant decrease, whilst the O_2 level is basically the same. Given the fact that the overfire air flow and fuel feed rate increase with the boiler load and the measured O_2 level is the same, the decrease of combusting gases yields corresponds to a more intense combustion at higher boiler load. Since the global air to fuel ratio doesn't change significantly with the boiler load, the only parameter influencing the gas phase combustion quality is the turbulence intensity.

Table 2. Measured gas concentrations inside the furnace

Measurement point	P1			P2		P3	
Boiler load (%)	65	80	100	80	100	80	100
O_2 (%vol.)	5.1	5.2	5.3	9.9	8.0	2.2	0.6
CO_2 (%vol.)	13.6	13.4	13.0	10.4	12.4	16.7	17.8
$CO^{\dagger}$ (mg/Nm^3)	58650	59335	59713	10103	4261	25638	38884
$NO_x^{\dagger}$ (mg/Nm^3)	170	126	141	252	253	158	117
$VOC^{\dagger,*}$ (mg/Nm^3)	8385	7610	8447	778	180	480	1870
$CH_4^{\dagger,*}$ (mg/Nm^3)	6653	5376	5054	515	130	340	1353
$SO_2^{\dagger}$ (mg/Nm^3)	1494	1461	1567	156	56	140	445

† expressed at 6%vol. of O_2
* expressed on wet basis

The evolution of the gas concentrations is different in the direction defined by the points P2 and P3. Thus, the combusting gases yield is slightly decreasing at 80% load, except for the CO, which is 2.5 times higher at point P3. However, perhaps the most interesting evolution is that of O_2 concentration, which at point P3 is 2%vol. at 80% load, and drops to zero at 100% boiler load. Therefore, it seems that at 80% load, compared to the full load, the local conditions (temperature, air to fuel ratio and mixing) at point P3 correspond to lower devolatilisation and combustion products yields of the flying fuel particles. Moreover, the abundant presence of CO could be related to a higher rate of devolatilsation/char burnout at this level compared to the P2 point, where the main reactions are due to gas phase combustion. This suggests that the fine fuel particles carried by the gas flow are concentrated on this side of the furnace (*i.e.* delimited by the point P3 plane). This is further supported by the results obtained at full load, where the flying fine fuel particles concentration seems higher, resulting in increased combustion gases yields.

Concerning the evolution of NO_x and SO_x concentrations at point P3, the local small amount of O_2 indicates that these species are mainly produced through heterogeneous mechanisms. The decrease of O_2 and NO_x yields, as well as the increase of SO_2 concentration at full load supports the assumption that there is a higher concentration of fine fuel particles carried by the bulk gas flow at this level of the furnace. Since the fraction of fine fuel particles (< 1 mm) is below 1%wt., the presence of high quantity of flying unburned particles is mainly due to the high fragmentation rate when passing through the flame.

4.2 Flue gas concentration at chimney

The time interval for one measurement of flue gas concentration was 2 hours, the results given in Table 3 below are averaged over this duration. The measured temperature and flow rate of flue gas show the same trend as the boiler load, their values corresponding to normal operation of the installation.

The evolution of the flue gas emissions seems independent of the boiler load, except for the CH_4, SO_2 and HCl yields. These last species show a decreasing concentration with the increase of the thermal load of the boiler. In order to provide an extensive analysis of these trends, the results obtained at local level (see Table 2) together with those at chimney are not sufficient, further information being needed, such as local temperature, local concentrations (also between P2-P3 points and the stack) and/or elemental balance (including solid effluents). However, the presence of methane and higher O_2 level in the flue gas at 65% load indicates a bad mixing between the volatiles and the combustion air.

As can be observed in Table 3, the total unburned hydrocarbons amount has a particular evolution. Its concentration drops to zero when passing from 65 to 80% load and increases at a level superior to that recorded for 65% load when the boiler is at full capacity. If the explanation for the THC yield at 65% load could be the same as for methane, it is difficult to argue for the measured value at full load. In the latter case, one assumption would be a slight decrease of air to fuel ratio at local level, which could entrain a higher local concentration of THC. Moreover, if this would occur in a region from where the conditions (especially temperature) are not optimum anymore to completely burn this type of compounds, then the measured concentration at the stack may be higher than expected. This could be also related to the quantity of fine fuel particles that are entrained by the main gas flow within the furnace (see above). Another possibility may be the change of the biomass composition for the same air to fuel ratio. Unfortunately, this assumption cannot be verified, since the biomass samples for 65 and 80 % loads have been significantly altered during their transport and storage.

Table 3. Measured flue gas concentrations

Boiler load (%)	65	80	100
Temperature (°C)	145	162	173
Flow rate (Nm^3/h)	66930	82710	94460
H_2O^* (%vol.)	18.8	18.6	23.6
O_2 (%vol.)	5.1	4.5	4.2
CO_2 (%vol.)	15.2	15.7	16.1
Dust† (mg/Nm^3)	0.44	0.6	0.44
CO† (mg/Nm^3)	103	130	116
NO_x† (mg/Nm^3)	206	187	225
THC† (mg/Nm^3)	0.44	0	0.83
CH_4† (mg/Nm^3)	0.85	0.01	0.01
SO_2† (mg/Nm^3)	0.23	0.19	0.18
HCl† (mg/Nm^3)	0.38	0.08	0.05
VOC screening			
Formaldehyde† (mg/Nm^3)			0.17
Acetaldehyde† (mg/Nm^3)			0.02
ΣBTEX† (mg/Nm^3)			< 0.11

* expressed on wet basis

† expressed at 6 %vol. O_2

The change of the biomass composition, at least for the moisture content, is suggested by the evolution of the water vapour content in the flue gas. The results show the same concentration for the 65 and 80 % loads, whilst its yield at full load increases by 5 %vol.

Concerning the dust, CO and NO_x levels in the flue gas, they show little difference between 65 and 100 % load. However, the results indicate that dust and CO concentrations are slightly higher at 80 % boiler load, whilst the NO_x level is lower. Again, due to its location, the information obtained inside the furnace (see Table 2) is not sufficient to explain this evolution.

Finally, for all the investigated thermal loads of the boiler, no PAH were detected at the stack. The same observation concerns the complete VOC screening that was performed at full load. Overall, the aldehydes and BTEX were at the detection limit. Only the formaldehyde and acetaldehyde were quantified, their values being also close to the detection limit.

5 CONCLUSIONS

A simple design easy to use in-furnace gas sampling probe has been developed and successfully used on a 45 MW_{th} spreader stoker biomass fired boiler, with no consequences on the boiler operation. The tests were carried out for three boiler thermal loads, 65, 80 and 100 % of its full capacity. The gas was sampled in three different points of the furnace, below the last overfire air stage. In parallel, a gas analysis was performed at the chimney. For the in-furnace gas concentrations, the following species were accounted: O_2, CO_2, CO, NO_x, THC, CH_4 and SO_2. The flue gas concentration measurements include the previous compounds plus the water vapour, dust, PAH yields. Also, a complete VOC screening was performed for the flue gas at full load.

The results show that the gas concentrations are rather independent of the boiler load, whether if it’s at local level (inside the furnace) or global (at the stack). This confirms that the choice of the operational parameters is well adapted to the variation of the boiler capacity. Nevertheless, the recorded evolution of gas yields within the furnace shows a certain dissymmetry along the boiler length (from point P2 to P3 on Figure 3). One possible interpretation is the presence of fine fuel particles entrained by the gas bulk flow at higher rate than expected. In order to have a more accurate image of the evolution of gas concentrations, especially for SO_x and HCl, complementary in-furnace measurements situated at intermediate locations between the P2-P3 points and the stack are necessary, as well as an extended mass balance.

Even though the gas concentrations measured in the flue gas, they comply with today’s emission limits, their yields can be further reduced. Based on the results obtained here, the main issues that must be addressed in order to optimize this type of boiler have been identified, for instance the turbulence inside the furnace or the air staging strategy. Investigations are currently carried out using CFD tools.

REFERENCES

[1] Wang C., Wu Y., Liu Q., Yang H., Wang F. Analysis of the behaviour of pollutant gas emissions during wheat straw/coal cofiring by TG-FTIR. Fuel Processing Technology, vol. 92, pp. 1037-1041, 2011.

[2] Weissinger A., Fleckl T., Obernberger I. In situ FT-IR spectroscopic investigations of species from biomass fuels in a laboratory-scale combustor. Combustion & Flame, vol. 137, pp. 403-417, 2004.

[3] Williams A., Jones J.M., Ma L., Pourkashanian M. Pollutants from the combustion of solid biomass fuels. Progress in Energy and Combustion Science, vol. 38, n° 2, pp. 113-137, 2012.

[4] Florea T., Caillat S., Taupin B., Baudoin B. Numerical and experimental study of gas combustion in a 400 kW woodchips moving grate furnace. In Proceedings of 9th European Conference on Industrial Furnaces and Boilers, Estoril, Portugal, 2011.

[5] Florea T., Taupin B., Caillat S., Souchon D., Kervella E., Nicol F. In-furnace gas sampling for analysis applied to a biomass grate fired boiler. In Proceedings of 4th International Symposium on Energy from Biomass and Waste, Venice, Italy, 2012. ISBN 978-88-6265-006-9

[6] Brink A., Koschack R., Laurén T., Hupa M. Measurements of gas and surface temperatures in an industrial bubbling fluidized bed boiler firing moist bark. In Proceedings of 9th European Conference on Industrial Furnaces and Boilers, Estoril, Portugal, 2011.

[7] Vainio E., Brink A., Yrjas P., Hupa M., Kajolinna T., Vesala H. In-furnace measurements of gaseous species in a 107 MW_{th} BFB boiler. In Proceedings of 9th European Conference on Industrial Furnaces and Boilers, Estoril, Portugal, 2011.

SIMPLIFIED PERFORMANCE EXERGY ANALYSIS TOOLS FOR THERMAL POWER PLANTS

J. Taillon [a], R. E. Blanchard [b]

[a] *ANDRITZ, Carbona Inc.Tammasaarenkatu 1,FI-00180, Helsinki, FinlandEmail: jean.taillon@andritz.com*

[b] *Loughborough UniversitySchool of Electronic, Electrical and Systems EngineeringLE11 3TU, Leicestershire, UK Email:r.e.blanchard@lboro.ac.uk*

ABSTRACT: There is an unequivocal support for exergy analysis in thermodynamics literature. However, the industry at large relies on energy conservation principles. Exergy barriers are its complexity and seemingly futility when power, heat and fuel are multiplied by their costs rates. This paper demonstrates the weakness of the current industrial approach and introduces novel graphs which will facilitate the use of exergy in the industry. Graph 1 combines overall, electrical and thermal exergy efficiencies. Graph 2 splits thermal exergy efficiency into its heat quality (2^{nd} law) and thermal losses (1^{st} law). The model was tested on 21 existing and design phased thermal power plants based on biomass gasification and combustion. The main results are; (1) on an energy efficiency basis, a biomass combustion plant rank 1^{st} but slips to 16^{th} position on an exergetic basis (2) on an exergy basis, a natural gas power plant rank 1^{st} but splips to 9^{th} position on an energy basis which makes sense because 30% exergy is destroyed with natural gas while 50% is destroyed with woody biomass (3) condensing power plants can be more efficient than cogeneration plants, a fact undetected by the current approach. These examples demonstrates that energy based efficiency may give erroneous results. Finally, these novel graphs provide; easy to understand (graphs instead of lists), true (1^{st} & 2^{nd} law of thermodynamics) and complete (overall, electrical and thermal efficiencies) measures of performance for thermal power plants.

Keywords: *Exergy, Energy, Efficiency*

UTILIZATION OF WOOD FUELS IN FINLAND

Arto Rummukainen, Martti Flyktman, Esa Ylitalo, Leena Petäjistö & Tuomas Nummelin*
*Finnish Forest Research Institute (Metla) / *VTT*
Correspondence: Metla, Pb. 18, 01301 Vantaa, Finland
*Firstname.Lastname@metla.fi / *Martti.Flyktman@vtt.fi*

ABSTRACT: There were 827 power plants in Finland in 2011 utilising mechanical forest energy like forest chips, cutting debris, stumps, small size whole trees, bark, saw dust, industrial waste wood, recycled wood, pellets and briquettes. Black liquor from pulp mills is a very important forest based chemical fuel, but it is excluded from this study. Status of the utilisation of forest fuels is updated every year by an enquiry, which Metla sends to power plant owners. Less than tenth of the number of power plants produced combined heat and electric power (CHP), the majority only heat. Heat is used for domestic and district heating and industrial processes. The median heat plant produced 2 400 MWh with wood fuels. Utilisation of forest energy in a median CHP-plant was one hundred times bigger. When studying only plants utilising entirely or partly forest chips, the production with forest fuels is made either in small one fuel plants with median production 2 000 MWh or in large plants using many fuels side by side (median 10 000 MWh). Two thirds of forest chips are utilised in large heat and power plants. Power companies own 40 % of plants, one quarter is owned by forest industry and the rest by public bodies, forest owner's organisations and others. 40% of power plants utilised many fuels at the same time, one third only forest chips, 15% only pellets/briquettes, the rest only mechanical forest industry residuals. According to a separate enquiry power plants with no connection to round wood procurement were quite satisfied with the forest chips suppliers in 2012. One fifth of respondents had problems to get good quality chips or with pricing of the chips. More than half of answerers estimated that utilisation volumes of forest chips will grow in new few years. Chip volumes from forest industry were estimated to stay or decrease.

Key words: wood energy, power plant, fuel procurement

1 BACKGROUND

Forest based fuels have long been utilised in Finland. The climate change has been an important reason for Finnish State and Forest Industry to try to utilize renewable local forest energy more intensively and even to replace imported fossil fuels with it [1]. Round wood based fuels like black liquor, bark and by-products of mechanical forest industry, not to mention domestic fire wood have long been utilised. Over ten last years the utilisation of forest "by-products" of round wood harvesting, like cutting debris, stumps and small size whole trees, have been increased [2]. Increased forest energy utilisation has created new markets and players to wood markets. There is time to explore the forest energy business by building value networks of utilisation and procurement of forest fuels. European Union funded USVA-project has partly financed this study, which look into the needs to develop fuel procurement part in the forest energy value chains [3].

2 DATA

2.1 Power plant fuel enquiry

Metla collects yearly official Finnish statistics about utilisation wood based fuels [2]. Enquiry is sent to all known energy or power plants, which utilise forest based fuels (e.g. forest chips (from cutting debris, stumps and small size whole trees), residual chips from mechanical forest industry, sawdust, bark, recycled wood etc.). In 2011 there were 827 plants, of which 510 utilised forest chips. Some minor energy plants may be missing from the data. Statistics describe only utilisation of wood fuels, the total capacity of plants may be much larger because of other fuel types like peat, and coal. Statistics on other wood based fuels like black liquor or pellets base on enquiries of Statistics Finland [4].

2.2 Fuel procurement enquiry

In April 2013 an email enquiry was sent to 515 power plants utilising forest chips. Excluded plants operated by big forest industry companies, which have own procurement organisation for purchase of round wood. So, the targeted power plants do have to organise their energy wood procurement without help of own round wood organisation. Part of enquiries returned because of some problems with the email address, so 426 power plants received enquiry. With 124 answers the reply per cent was 29. This study deals with the answers of 95 plants, which announced to utilise forest chips. The rest utilised only mechanical forest industry chips and other forest based fuels. More than 70 % of these produced only heat energy, the rest both electricity and heat energy. All repliers did not answer to all questions.

3 WOOD FUEL MARKETS

3.1 Origin and supply chain

Wood based fuels are either mechanical sections or their compilations of tree parts or they are solid, liquid, plastic or gas fuels processed from tree parts by gasification or chemical processes. Forest chips are made by cutting or crushing tree parts (including stem wood, stump, branches, bark and/or needles or leaves) on stand, on roadside, on terminal or on the yard of power plant.

In Finland about 80 % of commercial removals come from non-industrial private forest owners' forests [2]. The wood trade is made as stumpage sale, where buyer get proprietary rights to all wood assortments and also organises the harvesting and transport. Forest industry and State Forests together organise almost 90 % of cutting and even larger share of transport of round wood. So, most energy wood resources and the whole black liquor business are bound to round wood procurement of three biggest international integrated forest industry companies and State Forest. Private sawmills buy smaller volumes and produce forest and industry chips and bark partly for pulping partly for energy use. Some independent harvesting organisations supply forest energy. Some power plants have own fuel procurement organisation. Some smaller plants can acquire all the needed fuel from own forests. Firewood for domestic use is mostly harvested by forest owner self. Beside that there are specialised firewood deliverers [e.g. 5]. In large; most forest energy comes through the large harvesting organisations, but locally also smaller players have relevance.

3.2 Structure and size of business

Finland has a quite diverse energy portfolio. Various forest energy sources together are the second most important energy source after oil [4]. Though, the volume of forest energy depends much on the success of forest industry. The largest single forest energy source is the black liquor from pulp mills and the second largest are the industrial wood residues. Small size energy wood and small combustion fire wood are not so dependent on forest industry's volume.

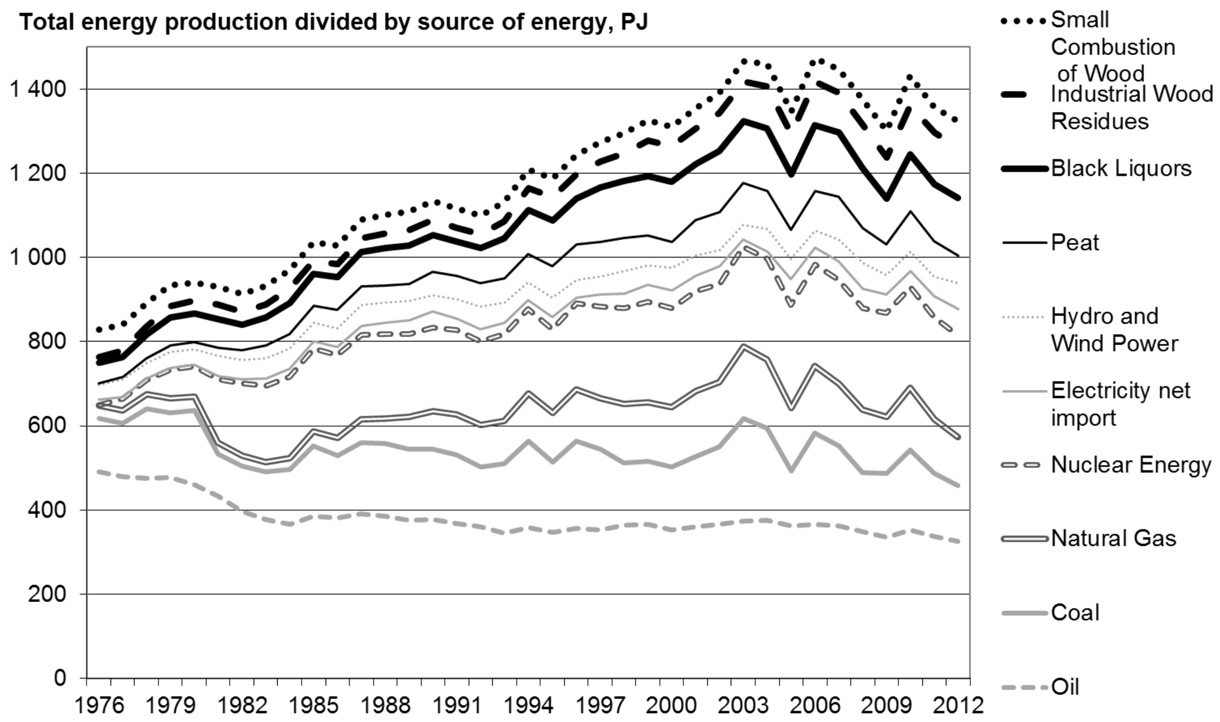


Figure 1. Development of Finnish total energy production by energy sources 1975-2011 [4].

In 2011 round wood harvesting brought 59 mill m^3 wood to industry, of which over half goes to chemical forest industry. Besides round wood it is harvested almost 7 mill m^3 cutting debris, stumps and small size whole wood. Firewood for domestic use is cut 6 mill m^3. Yearly import of wood is 10 mill m^3 [6]. Almost 2 mill m^3 recycling and waste wood is used for energy production per year. Part of this material has to be burned under monitored conditions.

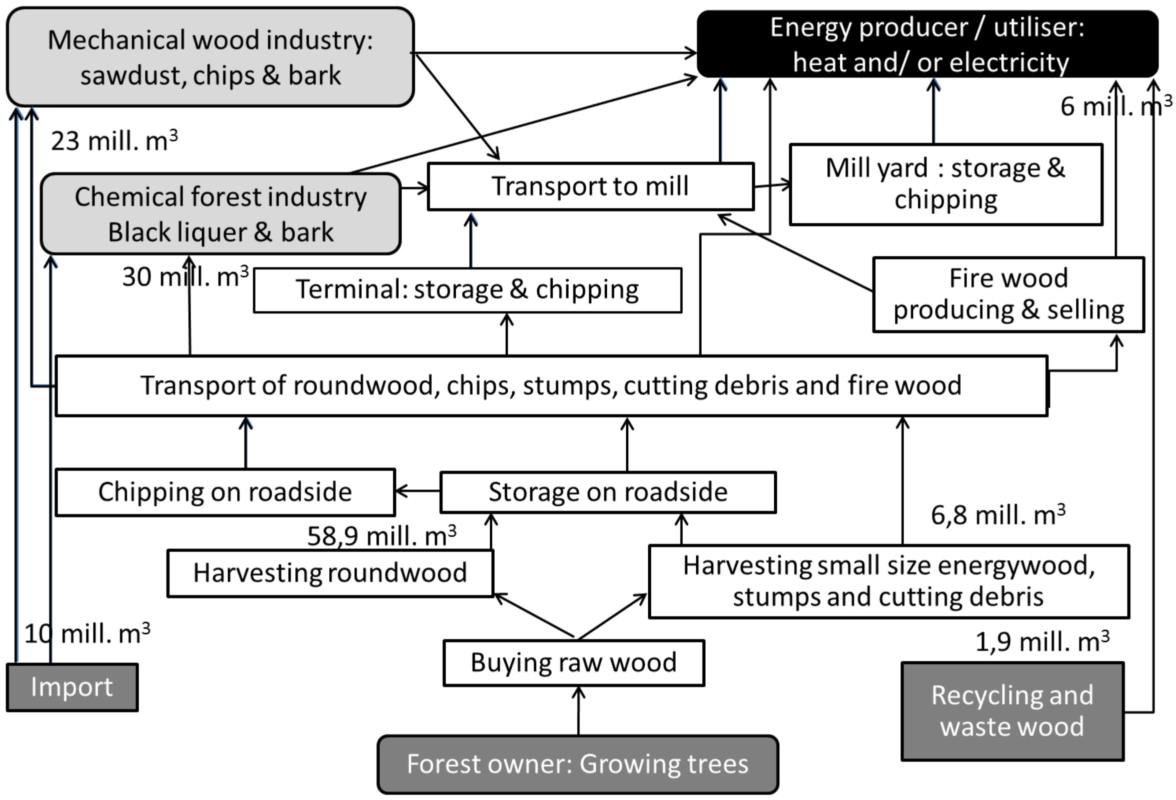


Figure 2. Forest product flows in 2011 in Finland [6,7].

4 POWER PLANTS UTILISING MECHANICAL FOREST ENERGY

4.1 Power plant size and fuel selection

Total mechanical forest energy (black liquor excluded) output in 2011 was in Finland according to the Metinfo-questionnaire 32 TWh [2]. Almost 80 % of that was burned in power plants which utilised more than 50 000 MWh forest energy fuels per year. Number of these large plants was only 12 % of total number of plants utilising forest energy. Over half of these large plants produced combined heat and electricity (CHP). So the rest more than 700 power plants utilised only about 20 per cent of the total forest energy. They all produced only heat energy.

Reminder: Because of the limitation of questionnaire, it was not possible to get data of what other fuels beside forest energy was utilised. So, all the numbers of utilisation and plant capacities are based only on the mechanical forest energy volumes during the year 2011.

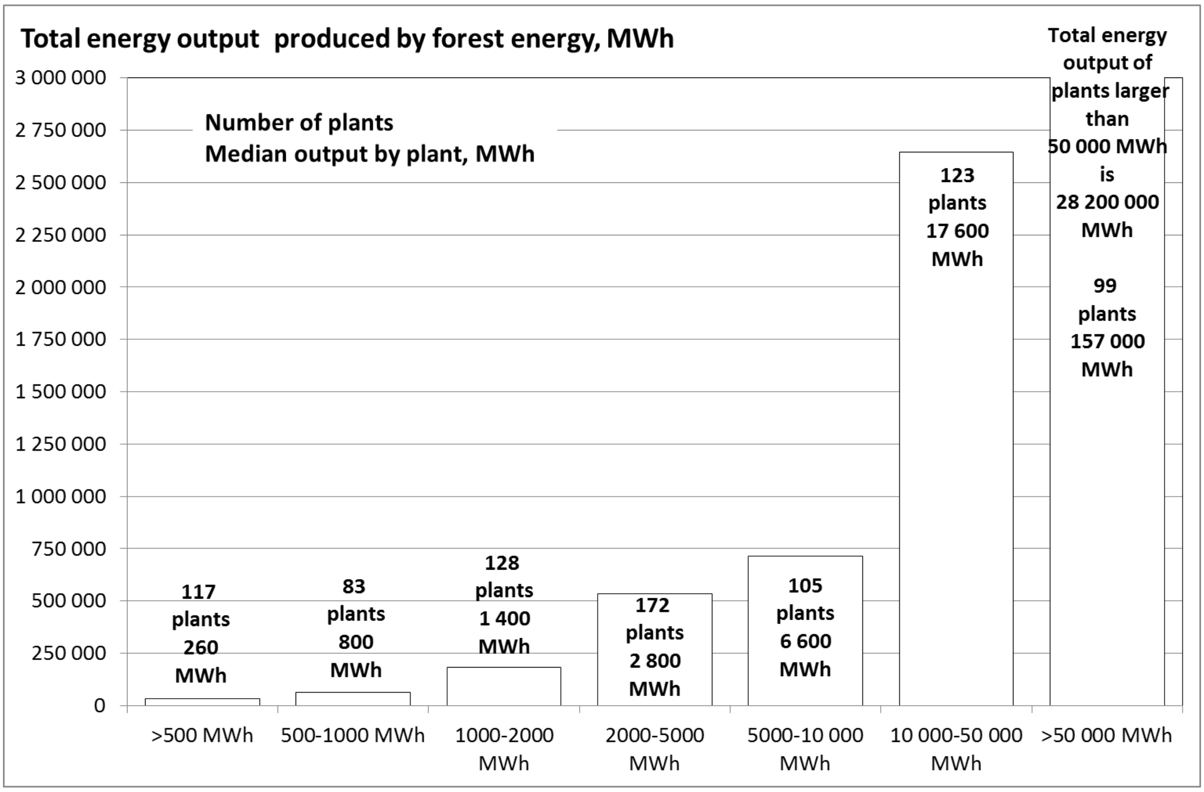


Figure 3. Total energy produced by forest mechanical energy fuels by the volume of forest energy utilization of a plant in 2011. Number of plants and median utilisation are given in figure.

Mechanical forest energy comes in various forms, most generally as forest chips or wood rests and bark from mechanical forest industry. Small boilers usually can utilise only one or few types of forest energy. Larger boilers can often exploit different solid fuels, like wood, peat and coal. This offers place for inviting fuels to bid. Number of boilers in each utilisation size class varies only little. The largest number of plants utilised between 2000 and 5 000 MWh forest energy per year.

Power plants burning forest chips utilised in general more mechanical forest energy than plants not using forest chips. Two thirds of number of plants utilised forest chips was, but they utilised almost nine tenths of total forest energy. Forest chips are not too homogenous so the feeding to boiler and storage systems are not the simplest ones. Forest chips are popular in little larger one fuel systems and most popular on large many fuel systems.

About one third of all power plants utilising mechanical forest energy were utilising many forest fuels side by side. Anyway, they utilised 80 per cent of total mechanical forest energy volume. Power plants using many fuels were also utilising much more mechanical forest energy per plant than plants utilising only one group of forest energy. The structure of larger boilers makes possible to utilise many solid fuel types at the same time. Pellet and briquette boilers utilised least forest energy per boiler, 1 600 MWh. Forest chips is the only fuel for majority number of plants utilising only one fuel type. Plants burning only industrial chips, saw dust and/or bark utilised largest volume of forest fuel per boiler (2 800 MWh) of all singe fuel group plants. Only five plants burned merely demolition and recycled wood. The burning cycle must be controlled, because of threat of possible poisonous residues like creosote, arsenic, copper and chromium compounds, and thus only few plants fulfil requirements.

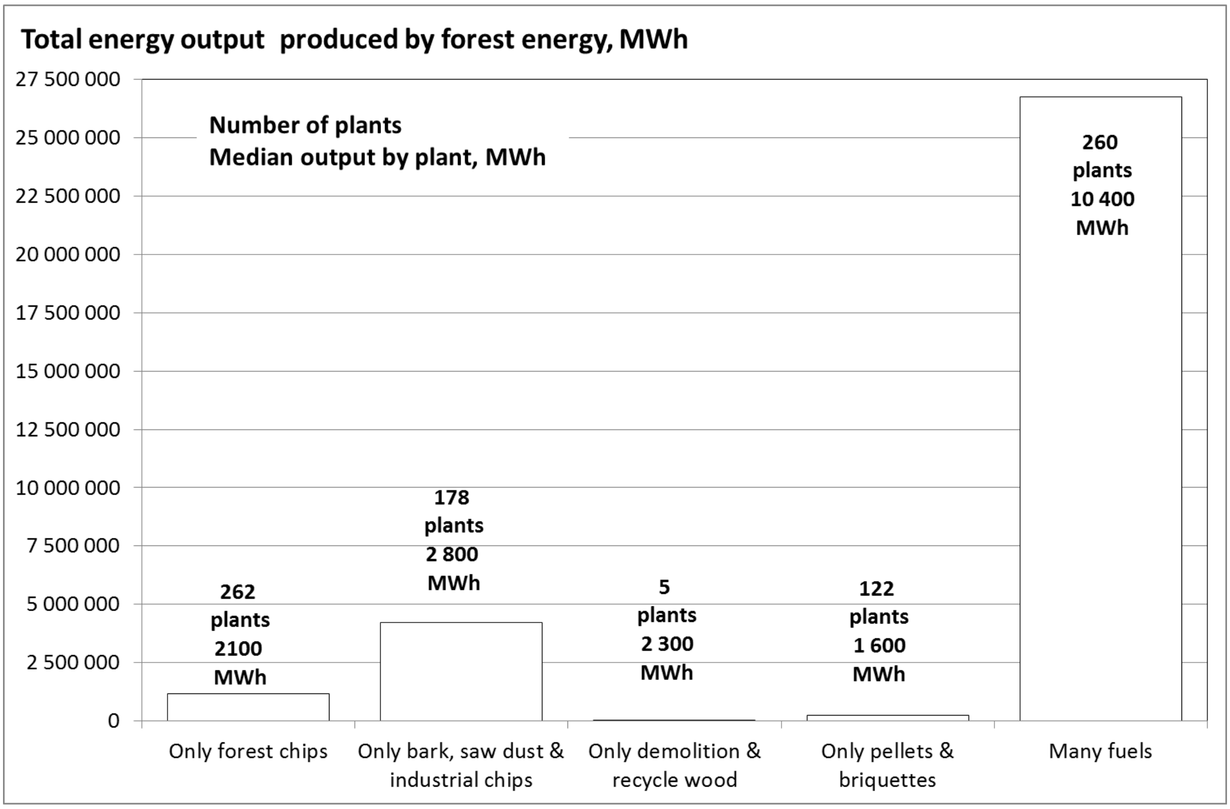


Figure 4. Total energy produced by mechanical forest energy fuels by single fuel type class in 2011. Number of plants and median production are given in figure.

One power plant utilised 7 mechanical forest fuel types at the same time. 500 power plants utilised only one fuel type. When the number of fuel types utilised at the same time increased, the number of plants decreased and the median of utilised forest energy volume grew up. Median utilised volume by one fuel plant was 1 700 MWh, by 2 fuel types 4 000 MWh and by 6 fuel types 572 000 MWh.

4.2 Plant ownership and supply connections

Three quarters of power plants were owned by limited companies. Second largest owner group was public communities and institutes. Other less organised company forms get third position and cooperatives fourth. One small, but interesting group are Forest Management Associations (FMA) and Forest Owners Associations (FOA). They own 8 energy plants and are also in charge of the fuel procurement. When measured the median size of power plant (according to the utilised forest fuel volume) the plants owned by FMA/FOA is largest (6 800 MWh) by all ownership groups. Second come limited companies (3 700 MWh) and third cooperatives. Because the number of small plants is large, but the most production is made in large plants the average limited companies' plants are biggest following public institutes' plants. This is order also in the comparison of the size of the biggest plant. Limited company –group is largest, so it contains plants with many different purposes, even small ones. FMA/FOA-group is very uniform, so the variation in plant size is little.

Power plants' other connections beside ownership form may tell a lot about the target, operation form and fuel procurement of the plant. When we check out only plants, which utilise forest chips, largest number of them (278 of total 510) is owned by heat/electricity power companies. Also the largest utilised total forest energy volume belongs to power companies. Second largest forest fuel utilizer group is plants with ownership/connection to mechanical wood industry like sawmills and wooden house manufacturers. The median size (measured by utilised forest energy) of their plants is about 13 000 MWh, which is double larger than that of power companies' or that of forest owners FMA / FOSs organisations. Smallest average power plant size is by public communities and private single plants, which are owned for example by a market garden or a holiday resort.

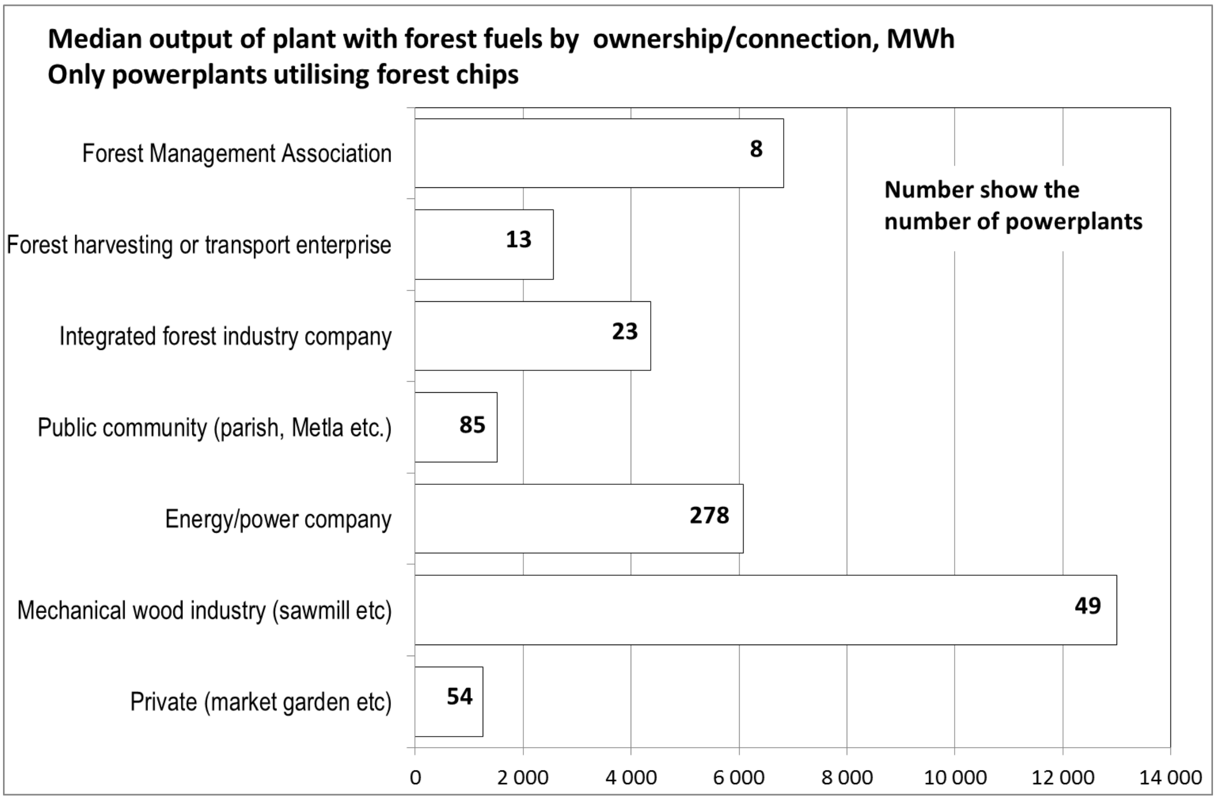


Figure 5. Median output of utilised forest fuels by ownership/connection to 2011. Includes only plants which buy also forest chips. Number of plants is given in figure.

Mechanical and integrated forest industry naturally gain largest share of fuel from their own processes and/or by their wood procurement organisation. Forest owners' organisations FMA/FOA have most likely based their operations to utilisation of their raw material knowledge and procurement resources. Power plants owned by harvesting or transport enterprises can utilise their competence in fuel procurement. Typically power companies, public communities and private plants have to rely on other's raw material resources and procurement organisations. So there is lot of space to different kind and size of operators in the forest fuel business, though the absolute major part is managed by traditional round wood procurement organisations of integrated forest industry companies.

4.3 Combined heat/electricity production

In Finnish cold winter climate it is economic to produce heat and electricity combined. In warmer climates there is no need to heat. To reach the same electricity and heat capacities by different processes we need one third more fuel compared combined heat/electricity production. Less than one tenth of total 827 plants utilising mechanical forest fuels produced electricity beside heat. Anyway heat /electricity plants utilised in total four times higher volume of forest fuels than only heat producing plants. The average yearly utilised forest energy volume is in an average heat plant 12 000 MWh but in an average combined heat/electricity plant 390 000 MWh. These large plants are typically utilising many types of solid fuels.

5 SATISFACTION TO FUEL SUPPLY

5.1 Procurement systems

Internet survey was send to power plants utilising wood fuels. It was excluded power plants, which were owned by organisation, which have own round wood procurement organisation.

Over half of the power plants (95 plants in total) bought all forest chips to be delivered at plant yard. Six repliers bought chips to intermediate storage and two bought chips from terminal. Three repliers bought self stands, which were harvested and transported it by own organisation. Two plants had own organisation to supply chips from their own forests.

Nine plants had some other solution to purchase the fuel. One bought the fuel supplied to directly to the feeding storage of the boiler. Three plants bought the energy trees from road side and a contractor chipped them. Two plants bought the trees also on road side, but chipped the material itself. Two plants actually bought heat energy from enterprise, which took care of everything. One plant bought the energy trees as shipped to plant yard and then chipped them by own machinery.

Almost three out of four plants (68 plants) had only one way to purchase fuel. 26 plants purchased forest chips or its raw material by using two or more ways. 17 plants of these last mentioned plants utilised one main way (at least 70 % of fuel volume) and one additional way. Five plants got fuel or its raw material by two ways. Four plants purchased fuel by more than two ways.

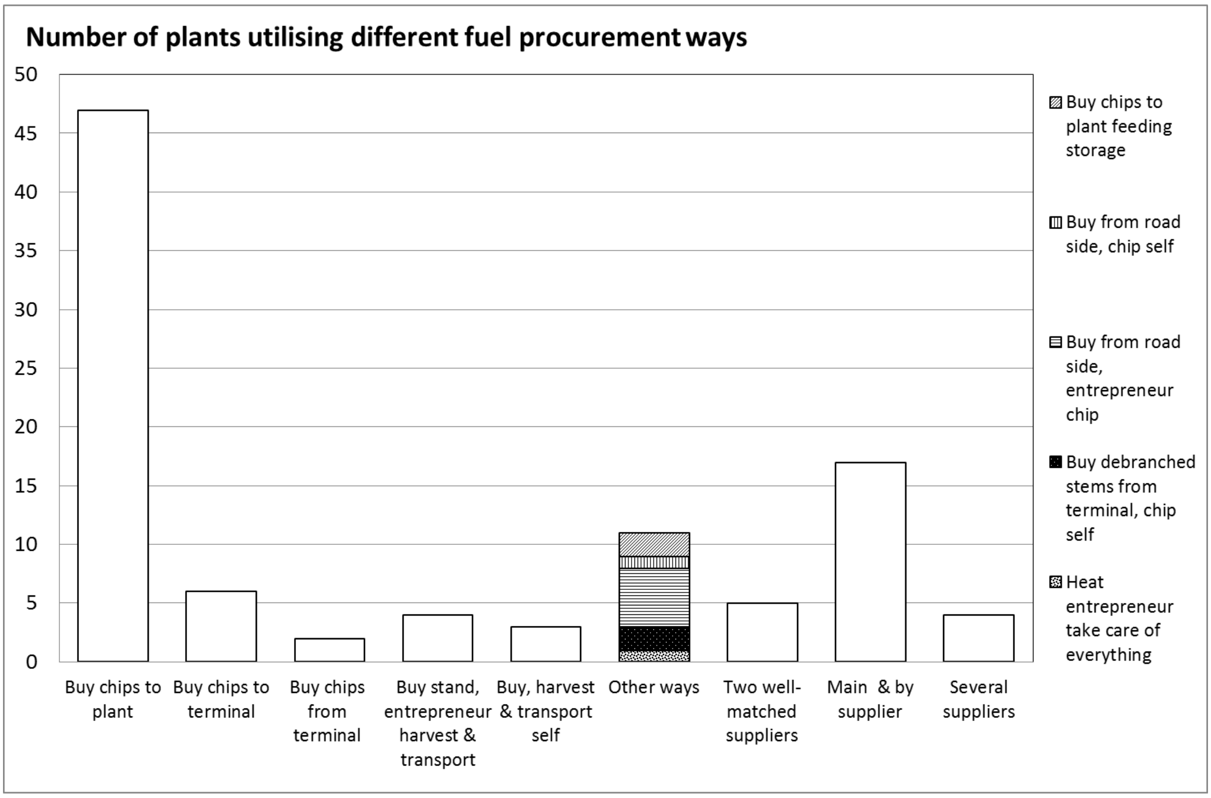


Figure 6. Ways to purchase forest chips to power plant 2012. Total number of answers n=95.

Preferring only one way to purchase forest chips is typical to plants, which use only little volumes chips. However even one bigger plant purchased forest chips buying it directly to its own mill storage. Though, in this case there were many suppliers. Utilising one main and another supporting purchase way occurred on both smaller and larger plants. In this way one can concentrate on main way, but at the same time the supporting way secures the operation if main way has problems. This seems to be very common way to diversify risk related to fuel procurement. The supporting purchase way may be also own purchase organisation, which upholds firm's own knowledge base. Number of plants which had many ways to purchase forest chips were only four and two of these were very big.

5.2 Problem points of supply operations

Respondents gave five point Likert scale how well different aspects of their forest chips procurement system work. Answerers of questionnaire were in 20 % of cases very satisfied and in 40 % satisfied on the actions of chips suppliers. Only few plants were not satisfied on suppliers.

Pricing of the fuel got the worst ratings, but even then 47 % of repliers gave grading well or very well. Quality of fuel had also poor rating. There 21 % of respondents found that it was problems or big problems in realisation of quality. Suppliers' cooperativeness and flexibility got problem marks only by 5 % of respondents. Technical implementation, timeliness of operations and reliability of deliveries got only 10 % problem marks. Quality of forest chips fuel depend on many aspects as e.g. size variation and moisture content, later depending also on weather conditions. Size and moisture content are often also bound to the price of chips. Maybe pricing system should guide the quality more often. All in all, most power plant owners saw that the most important question is to improve the quality of fuel. Respondents who had two suppliers had relatively highest share of problems in procurement.

Table 1. Respondents' grades for different aspects of suppliers successfulness in forest chips supplies.

	Realisation has worked very well	**Realisation has worked well**	**Not bad / not good**	**There has been problems in realisation**	**There has been big problems in realisation**	**Total, %**	**Number of replies**
Technical implementation, %	15	60	15	10		**100**	**82**
Timeliness of operations, %	22	50	17	10	1	**100**	**84**
Quality of fuel, %	10	45	24	17	4	**100**	**86**
Seasonality, %	18	41	24	16	1	**100**	**83**
Pricing, %	7	40	36	13	4	**100**	**84**
Cooperativeness and flexibility, %	24	57	14	4	1	**100**	**84**
Reliability of delivery, %	31	48	11	9	1	**100**	**85**
In average, %	**19**	**51**	**17**	**11**	**2**	**100**	

5.3 Choosing fuel supplier

Forty one per cent of repliers arranged bidding competition every year to choose suppliers. The competition was arranged every three years by 35 % of plants. The rest arranged bidding every fifth year or more seldom. Eight answerers didn't answer to this question.

Only six plants required some kind of certification from the fuel supplying operator. Reason for the certification requirement was to get a guarantee for the quality of operations, requirements of power plant customer or the way how the corporation operates.

6 FOREST ENERGY UTILISATION IN THE FUTURE

Most power plant owners foretold that utilisation of forest chips stays unchanged or increase in next three years. Only 5 % of respondents believed that utilisation volumes decrease. On the other hand almost one third of respondents foretold, that utilisation of chips from forest industry will decrease. Rapid increase of utilisation of chips from industry was predicted by no one. Chip volumes from industry were predicted to increase not so often than those from forest. That's sensible, because forest industry has long been in overcapacity problems [8]. Getting forest fuel on the other hand requires more organising and getting good quality is more laborious.

Table 2. Power plant owners' prediction of future forest energy utilisation volumes.

	Chips purchased from forest	**Chips purchased from forest industry**
Increase rapidly, %	6	
Increase, %	48	15
Stay unchanged, %	41	58
Decrease, %	4	18
Decrease rapidly, %	1	
Cannot say, %		9
Total, %	**100**	**100**
Number of replies	**89**	**71**

Most power plant owners foretold that utilisation of forest chips stays unchanged or increase in

next three years. Only 5 % of respondents believed that utilisation volumes decrease. On the other hand little larger share of respondents foretold, that utilisation of chips from forest industry is decreasing than it is increasing. Every tenth forest industry chips utilizers did not have any opinion of changes of utilisation.

Plans for new power plants contain frequently multi fuel boiler; one can utilise many different fuels. Fluidized bed boilers are suitable for different kind of fuels, especially circulating fluidized bed boilers (CFB). CFB boiler can use different types of solid fuels that include low quality coal, lignite's, coal blends, bark in pulp and paper mills, forests chips, peat and other bio mass products.

Finland has decided to decrease the use of coal in energy production [1]. There is an example; one power plant in Western-Finland has invested in the bio-gasification plant that has been constructed as part of the existing coal-fired power plant [9]. The plant is fuelled primarily with wood-based biomasses, particularly forest residue, and the produced gas will be combusted along with coal in the coal boiler. With the help of the gasifier about 25-40 per cent of the coal can be replaced with renewable energy. Other solutions to substitute coal are to use refines of renewable fuels, like wood pellets, torrefied pellets or synthetic natural gas from wood. Various Finnish companies are interested of these kinds of solutions.

Replacing oil with bio-oil from wood has started in Joensuu [10], but others are coming along. There is interest to small scale production of electricity by using gasifier and combustion engine, which are build by a couple of factories. In larger scale operations, sawmills could build steam turbine process and produce electricity by side of the heat energy.

7 CONLUSIONS

Forest based fuels composed in 2012 almost one quarter of total energy production in Finland [4]. In ten years it has grown up from one fifth. Forest based fuels are mostly available by-products of forest industry, but the utilisation of pure energy wood from forests has clearly increased. Forest based fuels are renewable and domestic, thus decreasing the CO_2-problems and giving work in local harvesting and transport organisations and harvesting machine and boiler production. Most of the forest fuels are purchased by existing round wood harvesting organizations, so the volume of industry affect directly to the utilisation volume of forest fuels. Supplying new power plants has though created some new wood buying organisations and new business opportunities.

The volume and type (heat/electricity) of operations determine the guide lines for boiler type. When utilising large fluidized bed boilers forest based fuels are competing directly with other solid fuels like peat and coal. Then the change between fuels can be swift compared to smaller grate boilers, which are built to one fuel type only. Choose of fuel procurement organisation is affected by the ownership of power plant and connections to harvesting organisations and forest owners. Considerable increase of utilisation of energy wood from first thinning or clearing of young stands, which are not necessary related to the round wood procurement, is tedious and may call for some new business forms and/or support of society. There are many plans and tests to replace coal and oil by renewable wood based fuels. In large cities this means that transporting of forest based fuels in form of chips is getting too expensive because of long distances. There is need to develop more energy intensive products for fuelling. Pellets, briquettes, torrefied wood and gas and oil products from wood, offer interesting development targets. In real world the opposite has realised, because of poor peat production summer 2012 and some political reasons, the utilization of coal increased 24 % in first quarter of 2013 [11].

Forty per cent of power plants arranged bidding competition to their suppliers every year and a quarter of them arranged bidding every five years or more seldom. When interviewing owner's opinions on their wood fuel procurement (organisation with direct connection to round wood harvesting organisations were excluded) about two thirds were in general satisfied to their suppliers' operations. Big problems had only 2 % of respondents. Quality and pricing of fuel caused most often problems. In general power plant owners had trustworthy suppliers, in a way the problems bound to same questions: best seasons of harvesting and burning are different, which may then bring quality problems and that bring questions of appropriate price. Total benefit of the procurement chain may need deviation of fastest and most efficient operation forms of both supplier and fuel buyer. Intermediate terminals/storages bring on costs, but they may offer much better possibilities to scheduling of operations and to keeping the quality of fuel on high level and thus also financial advantages. These kind of exercise requires tight cooperation between fuel buyer and supplier.

Power plant owners believe in forest fuels, over half of the repliers believed that the utilisation volumes grow during next five years. Though, that was only for chips from forest, only 15 % of respondents believed in growth of utilisation of forest industry chips. This show the considerable relevance of the domestic forest industry volume for utilisation of forest based fuels, where black liquor is still largest part. Though the tendency in forest industry is decreasing domestic production. Though, good points too, carbon dioxide emissions of Finnish pulp and paper industry decreased by one tenth, mostly because of increased utilisation of bioenergy in production processes [12].

8 REFERENCES

[1] National Energy and Climate Strategy - Government Report to Parliament on 20 March 2013. http://www.tem.fi/files/36292/Energia-_ja_ilmastostrategia_nettijulkaisu_ENGLANNINKIELINEN.pdf
[2] Ylitalo, E. Ed. 2012. Energy. In Finnish Statistical Yearbook of Forestry 2012. pp. 275-298.
[3] Research program: Developing program of renewable energy value networks and innovation environment 2012-2014. Funded by European Agricultural Fund for Rural Development. [Only in Finnish]. http://usvahanke.fi/
[4] Energy supply and consumption, Statistics Finland 2013. http://tilastokeskus.fi/til/ehk/index_en.html
[5] MottiNetti, helpoin tapa hankkia polttopuuta 2013 [Only in Finnish: A fuel wood selling internet portal]. http://www.mottinetti.fi/haku/
[6] Peltola, A. Ed. Foreign trade by forest industries. In Finnish Statistical Yearbook of Forestry 2012. pp. 325-356.
[7] Mäki-Simola, E. & Torvelainen, J. Eds. Removals and transportation of roundwood. In Finnish Statistical Yearbook of Forestry 2012. pp. 173-200.
[8] Paper and Paperboard Industry. Forestindustries 2012. http://www.forestindustries.fi/infokortit/Paper_industry/Pages/default.aspx
[9] Vaskiluoto bio gasification plant. Pohjolan Voima 2013. http://www.pohjolanvoima.fi/en/projects
[10] Combined heat and power production in Finland, Joensuu. Fortum 2013. http://www.fortum.com/en/energy-production/combined-heat-and-power/finland/pages/default.aspx
[11] Domestic energy replaced with imported energy, Statistics Finland 2013. http://tilastokeskus.fi/til/ehk/2013/01/ehk_2013_01_2013-06-20_tie_001_en.html
[12] Metsäteollisuuden ympäristötilastot vuodelta 2012. Metsäteollisuus 2013. [Only in Finnish, free translation: Environment statistics of forest industry in 2012.] http://www.metsateollisuus.fi/mediabank/606.pdf

DRYING PROCESS OF SMALL DIAMETER STEM WOOD FOR ENERGY PURPOSE IN ROAD SIDE STORAGE

Kolström Marja1, Routa Johanna2 , Pasanen Karri2, Ruotsalainen Johanna3 and Sikanen Lauri1*
1 University of Eastern Finland, School of Forest Sciences, P.O. Box 111, FI-80101 Joensuu, Finland
2 Finnish Forest Research Institute, Eastern Finland Regional Unit, P.O. Box 68, FI-80101 Joensuu, Finland
3 Finnish meteorological Institute, Kuopio Unit, Yliopistonranta 1 F, FI-70210 Kuopio marja.kolstrom@uef.fi*

The aim of this study is to compare drying process of energy wood storage piles in which some factors are different. These factors are two different tree species, covering and cover material. At the Mekrijärvi Research Station (University of Eastern Finland) has been built drying racks with continuous measuring systems. Determination of the moisture content is based on weight changes in the energy wood storage pile. This methodology gives possibility to monitor moisture changes much more detailed than earlier sampling methods. Method also gives the moisture of the whole pile, which is really challenging to determine by sampling methods

We aim to develop different calculating models to forecast the energy wood moisture content. Detailed data of the drying process under known weather conditions is available by way of the drying racks. Changes of moisture content can be connected to weather conditions, because there is a well-equipped meteorological station at the Research Station.

The models will support planning and operating of supply chains of energy wood. The drying processes in pine piles were very similar under uncovered conditions in summer 2012. In September 2012 the other pile was covered and very soon there was a sign of difference in moistening of the piles. In October 2012 we established two more racks in which we have small diameter stem wood of birch for energy purpose. These two piles are covered with two kind of cover; paper and fabric. During spring and summer 2013 we will study how the drying process varies between tree species, uncovered and covered piles, and two different kind of cover material. According to differences in the drying process of piles we can build models for two different tree species and covered and uncovered piles. The built models will be tested with data of moisture content of real storages in the field.

Keywords: energy wood, small diameter stem wood, moisture content, quality, storing, natural drying

FROM DESIGN TO OPERATION – INSTALLATION AND TESTING OF A SMALL-SCALE BIOMASS-TO-SNG TEST RIG FOR THE INVESTIGATION OF LONG-TERM EFFECTS

S. Fendt 1,, M. Gaderer 1, H. Spliethoff 1,2*

1 Institute for Energy Systems, Technische Universität München, Boltzmannstr. 15, 85747 Garching

Dipl.-Ing. Sebastian Fendt, Phone: +49 (0) 89 289 16207, Email: sebastian.fendt@tum.de

Dr.-Ing. Matthias Gaderer, Phone: +49 (0) 89 289 16292, Email: gaderer@tum.de

Prof. Dr.-Ing. Hartmut Spliethoff, Phone: +49 (0) 89 289 16270, Email: spliethoff@tum.de

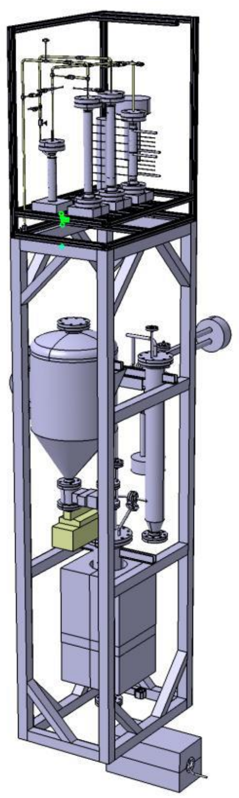
2 ZAE Bayern, Walther-Meißner-Str. 6, 85748 Garching, Germany

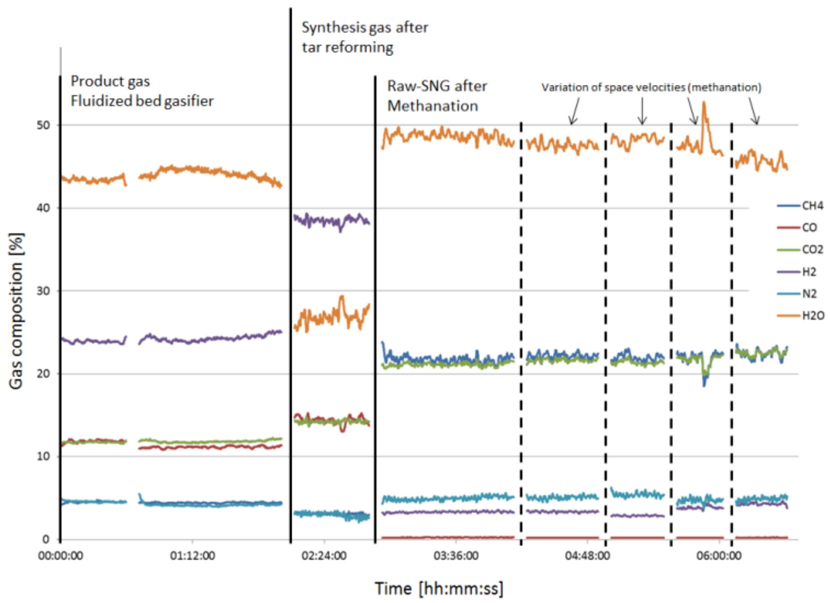
Synthetic natural gas (SNG) can be produced by thermochemical gasification of biomass and subsequent synthesis gas methanation and gas processing. For an industrial-scale process with high efficiency, the large plant size is connected to a number of disadvantages, whereas small-scale, SNG production units would minimize some negative aspects like the low energy density of biomass and local environmental impacts. Furthermore the small scale of the concept (0.5-5 MWth,in) guarantees a low CO2 balance of the process chain enhancing the eco-friendly character of the technology. However, the big challenge is to develop an economic technology to produce SNG from biomass. Therefore few, robust process steps have to be optimized for the (hot) gas cleaning and conversion of synthesis gas to SNG which fits the grid injection requirements.

The complete process chain from biomass to raw-SNG is therefore built up in lab-scale at the TUM. With the test rig, experiments to investigate the whole process chain and to carve out the loopholes of the concept are planned. The Figure on the right shows the new test rig.

Experimental results from previous tests are provided and discussed for the process steps gasification, hot gas cleaning and synthesis gas conversion.

The Figure on the left shows preliminary experimental results for the production of SNG obtained during a test campaign at the TUM. Measurements contain main gas components, tars and sulphur diagnostics as well as temperature and pressure monitoring.





PROFITABILITY OF THE SUPPLY CHAINS OF THE BIOENERGY TERMINAL ON DIFFERENT TRANSPORT DISTANCES AND VOLUMES

Hakonen, T. Seinäjoki University of Applied Sciences, School of Agriculture and Forestry, Tuomarniementie 55, FI-63700 Ähtäri tuomas.hakonen@seamk.fi, +358408300400

Abstract

The aim of the work was to investigate the effect of the transport distance and volume to the profitability of the supply chains of the energy wood. These factors were simultaneously examined. The four supply chains of delimbed trees were compared. Three of the supply chains went through bioenergy terminal and their costs were compared with the supply chain which is based on the roadside storage chipping and direct truck transportation to destination. The costs of chains were examined from the viewpoint of the owner of the terminal. Other parts of the supply chain were in the possession of the subcontractors.

In the study a simulation method was used. There was a separate simulation model for all the supply chains. The simulation models were run on the different starting values of the transport distance and transport volume. The results were compared with each other. In all the simulations 30-day duration and the steady energy wood flow were reached for. The cost and capacity factors in the simulation models were obtained from the forest energy organizations and from earlier studies. The chosen basis for cost and capacity factors was the situation which prevails in the field. In the study the administration costs and the profit margin were standardized to a certain level from the total costs. This way it was possible to examine the potential competitive strength of the supply chains.

At any transport distance and volume that was examined in this study the truck transportation chain which goes through the terminal did not reach the same cost efficiency than the chain which was based on roadside storage chipping and direct truck transportation. The railway transport from the terminal was more profitable than the direct truck transportation from roadside storage at its shortest distance of 70 km. In the simulations where cost factors were decreased from normal level the railway transport was the most profitable supply chain even at transport distance of 55 km. These results were achieved with volume 15000 m3/month and direct transportation from the terminal to the plant. The results give support to the thought that the profit margins and/or the administration costs of railway transport are partly bigger than in the truck transportations. On the other hand with the longer distance to terminal and with the railway transport where the end transportation is taken care of with a truck, the results settle near the 150 km break-even point. This is equivalent to the results of earlier studies. The competition of the railway transportation possibly drives the practical competitive ability closer to the results of this study.

The results are suitable for a general examination of the profitability of the supply chains at different transport distances and volumes. Because the examination has been made from the viewpoint of the owner of the terminal, it is possible to estimate the reasonability of the terminal implementation. However, the costs vary in different situations. It is important to compare the cost and capacity factors before applying these results to a new situation.

Keywords: energy wood, delimbed tree, railway, simulation, logistics

BUSINESS CONCEPTS AND DEMOSTRATION

NEW VALUE NETWORKS OF BIOECONOMY

Outi Pakarinen
Jyväskylä Innovation Ltd
P.O.Box 27, FI-40101 Jyväskylä
outi.pakarinen@jklinnovation.fi

1 INTRODUCTION

In 2012 The European Commission adopted a strategy to shift the European economy towards sustainable bioeconomy. The main goal of the strategy is a more innovative and low-emissions economy. The action plan focuses on three key aspects: developing new technologies and processes for the bioeconomy; developing markets and competitiveness in bioeconomy sectors; and pushing policymakers and stakeholders to work more closely together [1].

According to European Commission, the term "Bioeconomy" means an economy using biological resources from the land and sea, as well as waste, as inputs to food and feed, industrial and energy production. It also covers the use of bio-based processes for sustainable industries. The EU bioeconomy already has a turnover of nearly €2 trillion and employs more than 22 million people, 9% of total employment in the EU. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries [1].

In Finland the Ministry of Employment and the Economy, Ministry of Environment and Ministry of Agriculture and Forestry are preparing the national bioeconomy strategy. The strategy will be approved by Finnish Government in autumn 2013 [2].

The new value networks of bioeconomy (Biotalouden uudet arvoverkot) is a project funded by the Finnish Ministry of Employment and the Economy. Forest industry future (Jyväskylä, Joensuu and Savonlinna), Energy technology (Jyväskylä, Joensuu, Vaasa), and Finnish cleantech cluster programmes (Lahti) are the three clusters participating the project. The project is coordinated by Jyväskylä Innovation Ltd.

2 AIM OF THE “NEW VALUE NETWORKS OF BIOECONOMY” PROJECT

The main aim of the project is to recognize and multiply the new value networks of bioeconomy. Especially the value networks, which have suitable operations for small and medium sized enterprises are on focus. The project group has recognized several value networks which are related to e.g. distributed renewable energy production, nutrient recirculation and new business opportunities for forest industry.

The steering group of the project has selected four potential value networks for deeper investigation in summer 2013. These value networks are related to small scale energy entrepreneurship, logistics and terminal business of RDF (refuse-derived fuel), wood-based pyrolysis oil and biorefining of waste cooking oil and fat to biodiesel and biogas in integrated concept. Preliminary results of the possibilities of value networks of wood-based pyrolysis oil and integrated biodiesel and biogas concept will be presented here.

3 REFERENCES

[1] European Commission 2012. source: http://ec.europa.eu/research/bioeconomy/news-events/news/20120213_en.htm (27.6.2013).

[2] www.biotalous.fi (27.6.2013).

NEW BUSINESS OPPORTUNITIES CREATED BY BIOECONOMICS CONVERSION

Petri Nyberg
Jyväskylä Innovation Ltd. / Forest Industry Future Cluster Programme
P.O.Box 27, FI-40101 Jyväskylä
petri.nyberg@jklinnovation.fi

ABSTRACT: Emerging global drivers show us that there is a clear, long term need to change the industrial order from first-pass consuming of the non-renewable resources into closed loop recycling industry which is based on renewable resources. Regarding the renewable resources that are available in forest industry these drivers can be classified as

1. Political and Socio-Economic Drivers
2. Resource Based Drivers
3. Demand-driven Drivers
4. Technology Drivers

Furthermore, these drivers produce needs for new biomass inputs, new products, services and technology providers, thus new business possibilities which usually start as small and medium size businesses but may lead into a rapidly growing business. (Figure 1.)

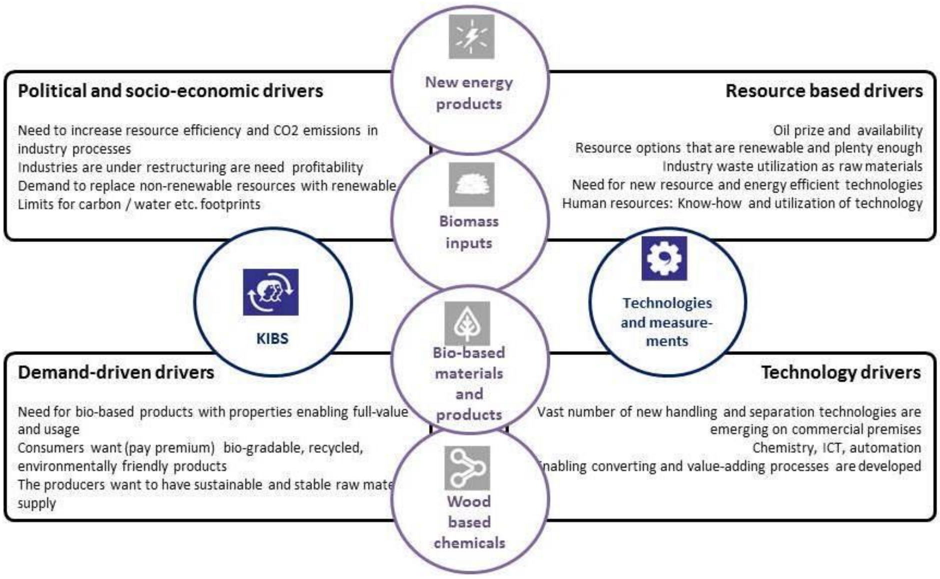


Figure 1. Drivers for bio economics and for new business opportunities

In this paper these new business opportunities are discussed and especially some examples what kind of new business possibilities are opening in new bio economics value networks (Figure 2.).

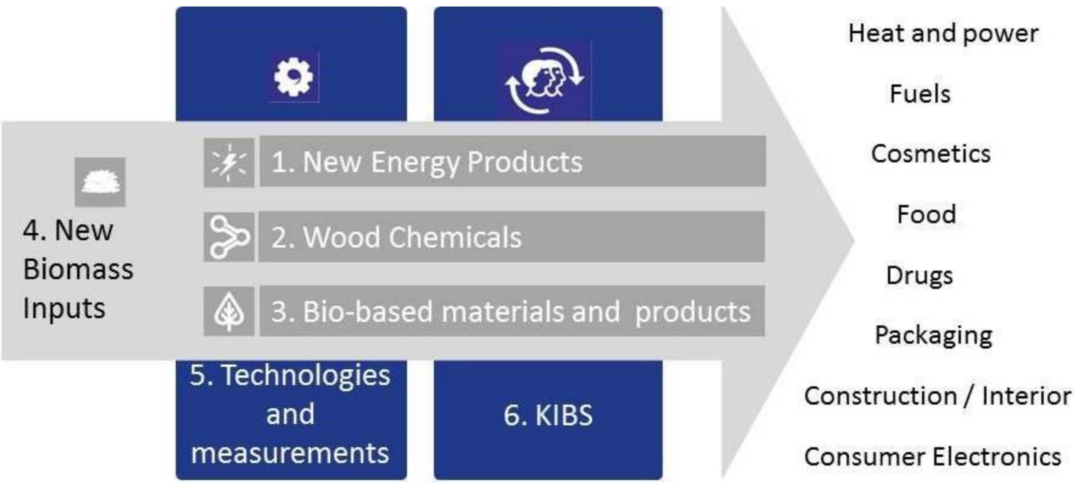


Figure 2. New business opportunities created by bio economics drivers.

CULTNATURE

A.K. Lutzenberger
ALRENE Engineering office
Am Brink 3, 22929 Kasseburg, Germany
akl@alrene.eu
F. Lehner
Paul-Klee-Str. 9, 45883 Gelsenkirchen
Franz.lehner@gmx.com

ABSTRACT: CultNature is a project to transform uncultivated and wasteland from old mining and industries in Biomass-Park areas, which are development axis in sustainable cities and regions. This project is developing the idea of the international architectural exhibition "Emscher Park" under consideration of the "Energiewende" and an ecological modernization of the industrialized society. Further CultNature line up the idea of the IBA Emscher Park on a new economic basis and is connecting it with new economic perspectives
Keywords: Biomass, Land Use, Sustainability, City Development

1 INITIAL POSITION

Disused mining and military areas as soon as old industry areas are often transformed in uncultivated or waste land which is in short and medium terms unattractive for a new economic use. The disusing of mining or the retreat of Military bases concerns many regions. This caused negative impacts of the economic development of these regions. A less of demand for industrial- and industrial real estates causes a non-using of these areas. Most of these areas cannot be used for residential buildings. All this impacts are responsible for a development of this area to uncultivated- or wasteland in cities and regions.

These problems are to observe in cities where the mining industry where shut down long time ago. For example in Bochum the last active mining closed in the year of 1973. 2011 Bochum has still more than 440 ha wasteland without new functions. Most of them are bigger than 10 ha. Such areas are relevant for the city development on one side, and on the other side they influence the townscape. Bochum has still ca. 900 ha of disused mining areas. More than a third are 40 years after closing the mining without a satisfying using. It has to be noted, that old mining areas can not be reused in a short time after stopping the coal production; there are procedures for safety and cleaning of the area and existing buildings and the rebuilding under control of the states mining agencies. But there is still the fact that more than a third of all mining areas are not used today, and in other cities in the Ruhr-region the situation will not differ. The surveillance made in Bochum in the last years will be make exemplary in cities where the mining will stop until 2018. This is expected because the cities in the Zone of Emscher and Lippe are having less of economical dynamic than the cities in the Hellweg-Zone. For these cities it is important to link CultNature with strategies that can sustainable advance the quality of the locations. The concept of CultNature is a solution for the discussed problems, which linked two known ideas. The first idea takes parts of the IBA-Emscher Park to develop wasteland to a park landscape. The ambition is an intra-urban advance of living- and location quality. These city-parks can be connected to a regional park landscape through the Ruhr-Region. The second idea is an economic use of wasteland and other uncultivated land to produce biomass for Energy. This solution can be realized without public funds because these biomass parks can be cost-effective. They will have a positive impact on townscape, City development and Quality of location.

In consideration of these circumstances it is obvious to link both ideas together. That means, that for the composition of these park landscapes crops are used that will have a positive aesthetic appeal and can be used economically worthwhile.

The main idea of CultNature is the transformation from wasteland to agro industrial used park landscapes.

Figure 1: An example of a biomass-park, which adds typical elements of park-landscapes with a production of energy-crops and the social approach of recreation areas. [1]

2 SUSTAINABLE AND INTEGRATED CITY-DEVELOPMENT

CultNature is orientated on the Concept of sustainability of the Brundlandt-Commission and the UNO-study from 1983 "World commission for environment and development". Transferred on city development this means: a sustainable city is a city that does not affect todays and future development of other cities and regions with their resource use.

Many experiences in the past ant the today's activities for Climate Change show that Sustainability is not accepted politically and social, if Sustainability stands against a economical development. At least this is guilty for the industrialized countries und their affected production- and economical culture. The Climate Change shows clearly, that the industrial affected structure of production and consumption is not sustainable in any way; further it endangered the natural basics existential. The CO_2-Emission or the use of nuclear power does not only cause this, above all it is the consumption of natural resources behind the planetary boundaries. This is from the ecological side not acceptable any more and therefore politically insupportable. These behave causes conflicts about the distribution of resources and of ecological costs and risks.

The Consumption of natural resources is the central problem of the ecological sustainability, may be it is the only existing adjusting instrument to achieve sustainability.

How experiences with the attendance of sustainability are showing, any effective programs are failing on the question of prosperity. That means, that sustainability is just achievable if it is linked with prosperity. And the only way seems to be Resource efficiency. With a drastic increase of resource efficiency about a factor 10 in the next two or three decades it may be possible that industrialized countries can hold their prosperity and developing and emerging countries can close the gap to the industrialized countries without increase the resource consumption and the GHG-Emissions.

With this background Cultnature is setting the ecological focus on resource efficiency, with the combination of energy efficiency and the IBA Emscher Park Motivation of Live Quality. Live Quality has its own value, because a less of live quality is a bottleneck for the economic development in the Ruhr-Region.

This is reasonable in the dependency of local quality in Germany in manpower of high-qualified labors. And this supply is determined by live quality.

CultNature changes the priorities in social and economic views. As it is seen now, the IBA Emscher Park did not focus enough on the economic dimension of the transition. This review is outgoing from today Problems and Problem-understanding which are quite different to the situation during the IBA Emscher Park.

CultNature gives a view of different possibilities and solutions to realize the above-mentioned concept of sustainability. On the level of city planning and development these possibilities are particularly the transformation of wasteland to bioenergy parks as an instrument

- For the development to a green city which generate an important part of their energy demand from Biomass. These cities are using wasteland for creating development axis for a sustainable city development.
- For the creation of attractive town scape while wasteland and uncultivated land will be transformed to aesthetic places that are attractive for leisure and sport activities.
- For a local attractively against trends; the development of industrial wasteland to industrial real estates.
- For the employment trend for people with a lower qualification and less of chances on the employment markets.
- For the development of a city culture with a balance of interests with the discussion of creation und use of wasteland and uncultivated land.

On the level of Quartier development CultNature gives opportunities in the use as an instrument for:

- The advancement of living- and working areas in Quartiers, which are affected from the retrogression of the mining industry, throw the transition of wasteland.
- The activation of this quartiers via participation of inhabitants in planning, creation and use of wastelands.
- The regional advancement of life chances with job creation and options for qualification. This is important for young and less qualified workers.

These conflict potentials are lead directly to the second main idea of CultNature, the idea of a integrated city development. This idea is propagated as a main item of city development in the Charta of Leipzig from 2007. The Leipzig-Charta is building in the Aalborg-Charta that was declared in 1994. In Germany, the Initiative "National City Development Policy", the Institution "Deutscher Städtetag" and the German City- and Community band implement the Leipzig- Charta.

Integrated City development in the meaning of the Leipzig-Charta includes a participation of all involved stakeholder in the process of city development. Disadvantaged Quartiers shall get more in the center of political activities. Also with the instrument of participation different positions shall be balanced.

The special focus for disadvantaged quartiers is to settle the unequal chances of involvement. The results of this approach should be a higher quality of city planning and development, more life quality, the protection of urban framework and at least a sustainable development.

3 PROJECT DEVELOPMENTLAYOUT

CultNatures Concept for Sustainability gives some guide lines to continue the project:

1. First aim of CultNature is to transform wasteland to biomass parks as much as possible. These parks must be productive in a middle and long term. These parks content further landscape elements, free and commercial leisure supply, living areas, and industrial real estates. This aim must be included in all planning and development of wastelands from the beginning. Economical activities must be ecological and social sustainable.
2. Wastelands, with no option for a industrial use in a middle and long term should developed with a high leisure value for defined target groups, so that life quality and the environment of the region is increasing.
3. All wasteland should be planned in a way, that, while keeping landscape architectural quality criteria and functional necessities, the best possible yields from energy crops are reachable. Biomass will be an important renewable energy source, but other options like Photovoltaic or wind energy can also be used, if it is economically reasonable.

A central item of a CultNature area is the link between an economically meaningful biomass- production with an ambitious landscape architecture. The concept of Cultnature is basically applicable for all industrial waste- and uncultivated land, and military conversion land in urban regions.

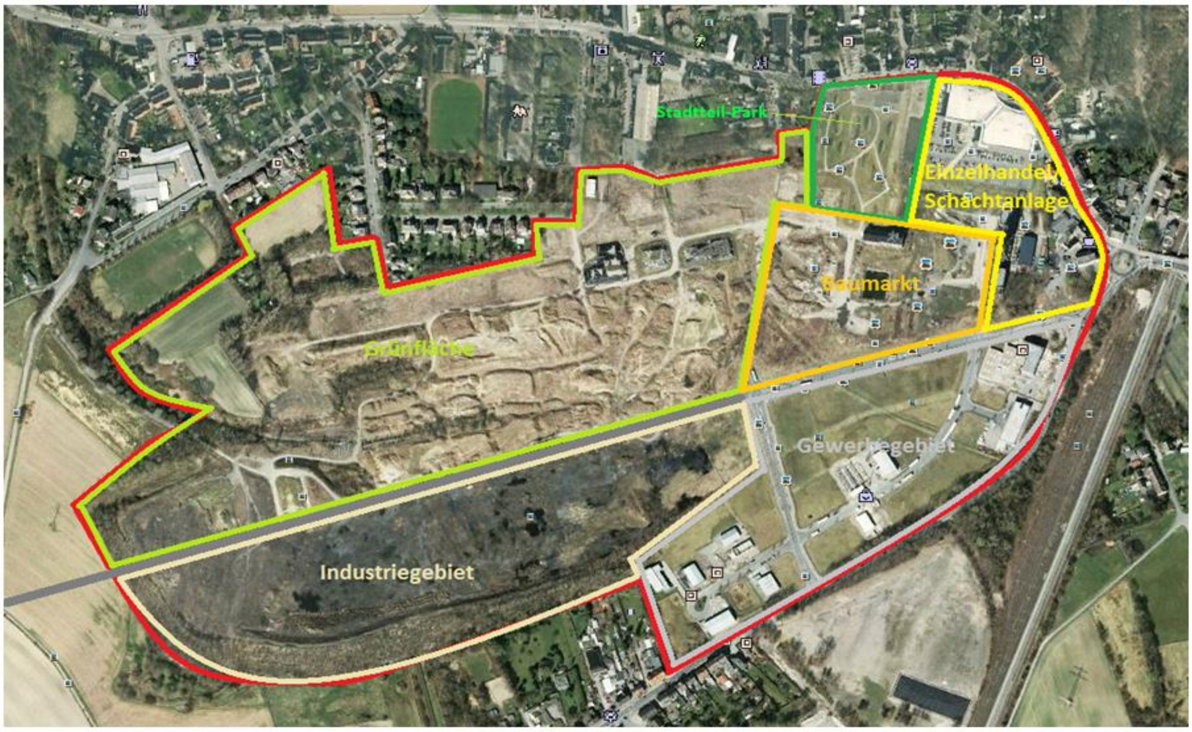


Figure 2: Industrial Wasteland in Dortmund [2]

4 BIOMASS

Since a few years there is still a debate of the sense of using Biomass as an energy source. To bring the debate on a point: The production of Bioenergy is only with the use of organic waste and biomass from residues ecologically worthwile. Otherwise Biomass males from the ecological point of view less of sense. This point is represented by the German National Academy of Sciences Leopoldina in her study; “Bioenergy: Chances and Limits”, published in 2012. The academy advises a development of all renewable energy sources except Biomass. This message was spread fast by the media.

The study of the academia just discussed biomass from agricultural production sides. Biomass out of urban wasteland was not included in their considerations. Thus, CultNature approach is still an option for a sustainable biomass use. Urban Biomass can still be an important energy source within the combination for a sustainable urban land use planning. The energetic potential of these areas are neglect in the study, but also in the socially and politically discussions of the last years. Biomass still has an important part in a renewable energy system, special as a source for heat/cooling and the electricity supply with “storable” energy.

CultNature is an option, where all the negative positions against biomass not apply. The approach of CultNature

is to use areas for the production of biomass that are uncultivated or wasteland without any other using options. These areas are not suitable for any kind of food production. Some of these areas where the mining industry march on rural areas with agricultural use, can bring back into the agricultural system to produce biomass without taken arable land out of food production.
CultNature brings options for the production of bioenergy, which are ecologically and economically sensible.
The Biomass production is in the concept of CultNature not the main item it is just an instrument. The aim is to value up wasteland into architectonic, functional, ecological and economical productive landscapes. The production and conversion of biomass should finance the transformation and guarantee the full coverage of follow-up costs. Follow-up Costs are generated by the preservation of the parks. Further the biomass production is a form of Catalyzer for the settlement of small and medium industrial real estates and other productive activities. At least the biomass production for bioenergy is a contribution of cities to resource efficiency.
After all, the dictum for the production of Biomass at CultNature-areas is to search for the economically best form of Biomass production in Line with the restrictions that are given by the targets of city development. Like mentioned above short rotation plantations and agricultural areas that are used for energy crops can be implemented in Park-Landscapes. This creates options to benefit with high-energy yields from the park areas keeping landscape architectural and town planning quality in mind.

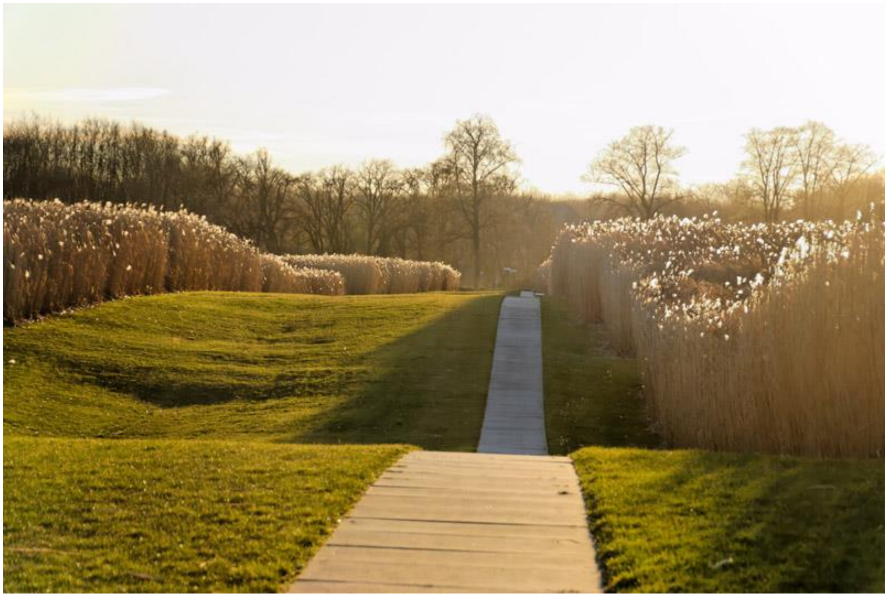


Figure 3: Project New Gardens of Schloss Dyck using Miscanthus as an landscape architectural element, (http://www.stiftung-schloss-dyck.de) planed and realised by Stephan Lenzen, RMP Landschaftsarchitekten (http://www.rmp-landschaftsarchitekten.de) [3].

The Production and combustion of biomass is not only a financial instrument, it has also a function as a promoter for the development of commercial and other productive activities. Further, the biomass conduces to a third aim of CultNature. CultNature - Biomass is a step in the direction of "City Mining". "City Mining" means, that preferably all organic waste and residues are used for material and energetic utilization. Infrastructure and logistics for sampling, separating and storage of this organic mass is a main requirement. CultNature can help to build up these infrastructures.

5 CROPS

Most of the areas of the CultNature project are areas with different grades of soil contamination. This problematic can be handled with three options. The first option is to cover the ground with a new surface soil or, using crops with a deep going root system to use a filling soil. This is the common way to make these areas reusable.
Second option is to leave these areas unused, so natural wild crop systems will discover these areas. Some areas with succession – forests are still existent.
The third variation is not common used for the old mining areas in North-Rhine Westphalia. It is the use of crops for soil rehabilitation. Reasons for the rare use of this methodology are the long lasting period and the reduced feasibilities of these areas. They cannot be used for sport parks, children's playgrounds, other leisure activities and buildings. This possibility is interesting for areas, which has to be used as green corridors from the landscape architectonical- and from the city planning side.
Further less and middle contaminated soils can be brought onto these areas for crop-soil rehabilitation. This option is financially attractive because income can be generated which is directly dependent of the grade of

contamination.

There a special crops which can be used for this soil rehabilitation with Phytodegradation . Crops assimilate Toxic matters in different ways. Therefore crops with a high assimilation rate and a concentration of these toxic matters in their biomass are particularly suitable for the Phytoextraction. Other convenient crops inactivate toxic matters with chemical processes inside the crop. The gain of these crops is the less of toxic matters Synthesis while the combustion ore digestion process.

With these context it is important that most of the energy crops that are feasible for CultNature will not assimilate toxic matters in high rates. Most of the crops can assimilate inorganic matters like heavy metals over their roots. High toxic matters like polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyl's (PCB) or Dioxins and Furans (PCDD/F) are chemical so high complex that most crops cannot assimilate them complete or just in components. Other crops are able to inactivate some of these toxic matters.

The production of biomass on old mining wasteland or other uncultivated land of industrial estates is not problematic from an ecological and healthy point of view. This includes crops that are spontaneous colonizing themselves like in Succession forests.

Cost models that are basing on agricultural experiences are not useable neither for city recycling areas nor CultNature areas. The production and business models are too different from this way of urban agriculture. So urban agriculture has to develop a new type of agricultural model. It is desirable to develop models for calculating these business models. Production models are influenced by a plurality of factors. For urban agricultural special models for every single area have to be calculated.

Under consideration of ecological aspects and Project requirements CultNature selected following crops as relevant for CultNature-Areas:

- Corn-Silage with in combination with undersown crops
- Sugarbeets
- Cup-plant *(Silphium perfoliatum)*
- Catch crops like alfalfa or clover
- Sunflowers, vetches
- Grain, like oat grass and rye
- Sorghum
- Szarvasi Grass, Miscanthus
- Short Rotation crops

All selected crops are variable and also in combination with an aesthetic value, landscape architectural instruments can design parks which changing views in the series of seasons.

CultNature can provide a framework to calculate pilot projects in different variations.

These experiences can be first components to create system modules that support a modulated development of production models for urban wastelands.

6 CONCLUSIONS

The ecological impact of CultNature is hard to estimate, special for climate effects in small regions like city quarters. It is still known, that green corridors have an important function for the climate of urban areas. So CultNature areas will still also have positive effects.

More important are the indirect socio-cultural climate effects. If CultNature establish urban wasteland as new green corridors and urban developing axis a transition in the behavior of urban leisure and mobility can have positive ecological effects. The establishment of more leisure attractiveness in urban areas can cause more leisure activities in the nearer periphery with a reduction of transport performances. The development of CultNature further can bring together Living and working areas.

The production of biomass on urban wasteland has a significant positive ecological effect. The agricultural production of energy crops often causes high environmental pollution causes by over-fertilization, Eutrophication, acidification of soils and a loss of biodiversity. The energetic use of residues and organic waste has positive results in the Eco balance. CultNature will have better results and effects as the conventional production of biomass on agricultural areas. Special the positive impacts on biodiversity will be measurable.

7 REFERENCES

[1] KLA – Kiparlandschaftsarchitekten with friendly permission of S. Günther.

[2] First Report CULTNATURE-Bio-Montan-Park NRW Dez. 2012 IAT Bochum.

[3] http://www.stiftung-schloss-dyck.de and http://www.rmp-landschaftsarchitekten.de

9 LOGO SPACE

Initiated and coordinated by:

CULTNATURE

IAT
Institut Arbeit und Technik

With:

KLA
kiparlandschaftsarchitekten

ALRENE
Ingenieurbüro

SUCCESS IN ENERGY SERVICE CONTRACTING

CEO Asko Ojaniemi
Benet Ltd.
Piippukatu 11, 40100 Jyväskylä, Finland
asko.ojaniemi@benet.fi
www.benet.fi

Background

In general, there is very good penetration of renewable energy in Finland, both in power and heating sectors. Today large utilities and major industries have multifuel boilers and in large extent they are using biomass when it is reasonably available, there are still smaller fossil fuel fired units where biomass fired units may be established. However, many industries and municipalities are not willing either to invest in biomass unit or are not willing to operate such unit. In those cases the solution could be energy service contracting.

Energy service models in Finland

Biomass based energy services started with fuel supply and plant O&M. Customer, typically municipality, invested in the plant and the service provider took care of the operation and maintenance as well as fuel supply. Many of the first service providers were co-operatives formed by farmers and forest owners, who had at least part of the fuel from own forests. Farmers could often use partly far/forest equipment they already had, and thus could lower the risks to start the service. This model is still in use and new contracts are made.

Later, service providers, were ready for higher investments and a model where service providers take care of the investment became more popular. In these cases the municipality usually took care of heat distribution to customers and service provider was whole heat supplier.

Customers started to demand even better service and today many customers do not want any part in heat supply, they want just to have heat supply agreement, where service provider takes care of everything. Industries, housing companies or municipal buildings are just ordinary district heat customers and service provider is running district heating operation fully.

Heat service providers are versatile organizations. There are nationwide utility companies having also heating services. On the other hand there are local small organizations having one or few plants. The organizational form can be limited company, cooperative or the service is part of some other business.

How to find energy service provider?

When looking service provider for larger unit, several MWth in capacity, usually nationwide operators are interested and the process can be quite straightforward competitive bidding process. On the other hand, to find a service provider for small operations, say less than 500 kWth, can be difficult.

Especially, if wood chip fired unit is preferred, the operation is very local. Fuel comes from nearby areas, and even unmanned plant needs someone in the region to attend the plant if need arises. In case, there are no existing service providers in the area, straightforward bidding does not work. There may be potential entrepreneurs in the area, but if you are not prepared, the typical bidding time of 40 days is very short time to get all ready in order to give firm heat price for long period of time.

In those cases, there must be preliminary work to support potential suppliers for the coming competitive bidding. Sometimes, there are advisory organizations to assist interested parties to make business plans and to prepare a competitive proposal. Sometimes, together with client, all known interested or otherwise potential parties are invited to workshop where coming project is presented.

Bidding process

Bidding process is very formal and all legal details should be followed. The legal process is straightforward and transparent and fair. On the other hand, if there are any flaws in formalities, there is great risk that losing party may cause delays to the process or possibly restart from the beginning. Because the bidding process is formal and to be able to make firm evaluation of the bids, everything must be clearly defined. This is good for the fair bid evaluation. On the other hand, if the terms of reference is very detailed and does not allow alternatives, then many good ideas the proposers may have, will not be included in the bids.

We are prefering not to limit the technology very tight but define the outcome of service clearly. Guaranteed service level, firm and clear pricing, clear responsibilities of parties etc.

Contracting

Contract formulation is critical. Contract must be clear and simple, all parties must easily understand the contract. Heating plants and heat distribution networks are long term infrastructure investment, contract period must be long enough to recover the investment. Technical lifetime of heating plant is 15 -20 years and the distribution network will last 50 years when properly maintained. Typical contract periods have been 15 – 20 years with option years. In some recent contracts the continuation is left entirely to market economy; if service provider is willing to continue and customers are renewing contracts the operation may continue with 6 – 12 month termination possibility.

Case stories

Below are three different examples how small private heating scheme was successfully started.

Hankasalmi Asema

This is a small village around Hankasalmi railway station. The initial idea came from housing companies. There were several housing companies with relatively old oil heating systems. It was time to do something. District heating was one option and initial calculations indicated that it could be competitive option. Town council was not keen to build DH infrastructure but was interested to join the service if it became available.

After few meeting with housing company representatives it was decided, that the desired option would be privately operated district heating service. Enough interested customers were found, suitable site for heating plant was located and municipality gave permission to place DH pipes on roadsides on municipal owned areas.

Wood energy advisors and other interested parties were informed beforehand in order to spread the word that such competition will open soon.

Competitive bidding was organized and several bids were received. Some larger operators withdrew from the bidding despite of initial interest. They calculated that they most likely were not competitive. The winning bid was low enough fulfilling the target to reduce heating costs. The offered heating price was below the variable costs of oil heating and thus final decision to accept the offer was easy for municipal and housing company representatives. The system is now running and few new customers in addition to initial group have joined district heating.

Aura municipality

Aura is typical rural town where most municipal and private buildings were oil heated. Municipality had evaluated the district heating possibility earlier, but it was never materialized as municipal service. This time municipal council was willing to try a private option. Competitive bidding was organized, several technically acceptable bids were received. The winning bid was from a group of farmes, who formed a new company for district heating service. The municipality reached both targets; lower heat bill and renewable heating.

Leivonmäki

This is a small rural village, where distances between major buildings are relatively long. The initial evaluation showed that conventional district heating may not be competitive. The solution was three separate small heating plants with small distribution networks. Here it was especially difficult find interested service provider. Initially we had several interested parties, but when it was time to give firm price, we received no bids. The municipality did not give up and we discussed with parties shown some interest, interviewed why they did not bid, what we could do to help. Finally we introduced a wood fuel specialist to experienced plant operator and they formed a joint venture to offer heating service in Leivonmäki. One party had access to wood fuel, had good skills in fuel supply and living in the town centre would make it handy to take care of the plants. Teaming up with more experienced plant operator gave the confidence to make firm offer.

Conclusions

Major district heating schemes are built in Finland. New greenfield schemes are relatively small where private heating service has proven to be a competitive option. In rural areas wood chip fired plants are often the winning option. In the more densely built areas there may not be suitable space for wood chip plant and there pellet is often the winning technology. In one case we have handled the heating service based on ground coupled heat pumps was selected. The renewability was secured by certificates that the power purchased will be produced in wood fired power plants. The conventional ESCO contract has not become very popular, because the customers do not want to take care of the plant in first place and they do not want to take care of the plant later either. The direct service contract in some form has proven to be operational. Several heat service providers are looking forward to add power production in their portfolio. It looks, that power produced and used on customer site could be economically possible, but small scale power fed to grid is not an option in Finland during present legislation and support schemes.

INDUSTRIAL ECOSYSTEM DESIGN IN PRACTICE. CASE: BIOGAS AS A TRANSPORTATION FUEL IN TURKU, FINLAND

Corresponding author: Anders Jungar, PBI-Research Institute for Project-Based Industry. Address: Aurakatu 1 B, FIN-20100 Turku, Finland. Tel.: +358 40 77 57 918. E-mail: anders.jungar@pbi.fi
Authors: Anders Jungarb, Anastasia Tsvetkovaa,b and Magnus Gustafssona,b
a Åbo Akademi University, Industrial Management, Piispankatu 8, FIN-20500 Turku, Finland
b PBI – Research Institute for Project-Based Industry, Aurakatu 1 B, FIN-20100 Turku, Finland

Purpose of the work: The purpose of this project was to design the industrial ecosystem for biogas-as-a-traffic-fuel. Based on the design, our goal was to create a concrete business case for introducing biogas as a traffic fuel in Turku, Finland. Furthermore, the objective was to define how this business can be expanded to other areas in Finland not covered by the existing natural gas pipe line network.

Traditionally, a lot of research effort has been put on optimizing technology on plant/factory level. However, we (PBI) believe that optimizing should be done on system level. In practice, we are talking about moving "from plant design to industrial ecosystem design" (see separate explanatory page). By the term industrial ecosystem we mean a network of industrial companies and other actors that exchange material and energy in a sustainable, nature-like manner; waste of one actor becomes input for another. This means closed-loop systems with smart use of natural resources in a financially, environmentally and socially sustainable manner. This paper demonstrates how such industrial ecosystems can be created to facilitate biogas use as traffic fuel.

Approach: The approach in this project was collaborative with close co-operation with all key stakeholders in the industrial ecosystem e.g. public transport authorities, local transport companies, vehicle sales, raw material suppliers for biogas production and the agriculture sector. Continuous focus was put on understanding the business logic and how integration of the above mentioned stakeholders should be done to ensure that biogas-as-a-traffic-fuel is turned into a profitable business for all parties involved.

Scientific innovation and relevance: The research proposes a new business type in which biogas production is only one part of the industrial ecosystem together with vehicle sales, transport, agriculture, and waste management. As the technology required for biogas-as-a-transportation-fuel is well-known, actual implementation is more dependent on the ability to integrate the right stakeholders rather than solving technical challenges. The latter points are addressed by this research.

Results: Concrete results from this research included:

- Industrial ecosystem design completed for biogas-as-a-traffic-fuel
- Business plan for implementation in Turku including e.g.:
- Pricing model for biogas
- Roles and responsibilities of key actors in ecosystem
- Plan for how to expand the business to other areas in Finland using Turku as a pilot case

Conclusions: To transform into a sustainable society, there is a need to improve the efficiency of material and energy cycles. This gives a big potential for locally produced, renewable traffic fuels such as biogas. However to bring the existing technologies to practice, integration and co-operation between key stakeholders, often having differing business goals and visions, needs to be well-defined. Introducing biogas-as-a-traffic-fuel is primarily not a question of over winning technological barriers but on understanding the business logic and the required business integration. PBI is currently actively involved in taking the biogas project in Turku to implementation phase.

---

[i] Member State biennial renewable energy progress reports (2011): http://ec.europa.eu/energy/renewables/reports/2011_en.htm
[ii] Renewable Energy: progressing towards the 2020 target (COM (2011) 31 and SEC (2011) 130)
[iii] In COM(2010)11 the Commission committed to reporting on the impacts of biomass sustainability regimes.
[iv] Member State biennial renewable energy progress reports (2011): http://ec.europa.eu/energy/renewables/reports/2011_en.htm
[v] (COM(2013) 18 final) http://ec.europa.eu/transport/themes/urban/cpt/index_en.htm
[vi] COM(2012)271
[vii] Commission proposal for revision the Energy Taxation Directive COM(2011) 169 final.